



Commercial Crew Program
John F. Kennedy Space Center

CCT-STD-1140
Revision: B-1

Crew Transportation Technical Standards and Design Evaluation Criteria

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1.0 Introduction

Under the guidance of processes provided by *Crew Transportation Plan* (CCT-PLN-1100), this document with its sister documents, *Crew Transportation Technical Management Processes* (CCT-PLN-1120), *International Space Station (ISS) Crew Transportation and Services Requirements Document* (CCT-REQ-1130), *Crew Transportation Operations Standards* (CCT-STD-1150), and *ISS to Commercial Orbital Transportation Services Interface Requirements Document* (SSP 50808), provide the basis for a National Aeronautics and Space Administration (NASA) certification for services to the ISS for the Commercial Provider. When NASA Crew Transportation System (CTS) certification is achieved for ISS transportation, the Commercial Provider will be eligible to provide services to and from the ISS during the services phase of the NASA Commercial Crew Program (CCP).

1.1 Purpose

In the course of over fifty years of human space flight, NASA has developed a working knowledge and body of standards that seek to guide both the design and the evaluation of safe designs for space systems. The purpose of this document is to inform potential Commercial Providers of the specifications, standards, and products/artifacts that NASA considers crucial to a successful development effort and to provide the Commercial Provider with NASA expectations, essentially the technical criteria, used in assessing these items to ensure they meet the intent of Sections 3.9 through 3.12 of CCT-REQ-1130.

The evaluation of technical standard requirements that utilize the "meet the intent of" language are addressed in this volume and may be satisfied through the use of alternative standards instead of the NASA, military, or industry standard listed. For these alternative standards, this document will be utilized to define the evaluation criteria that the CCP will use to determine whether the proposed standard is acceptable.

Discipline specific technical work products/artifacts (e.g., plans, analyses, reports, etc.) are also called out in this volume, along with the criteria that will be used to evaluate them. The intent is to identify products that NASA deems critical to the ultimate successful certification of a CTS. It is NASA's expectation that any Commercial Provider's successful development activities would already involve these products. It is not NASA's intent to convey a request for formal deliverables by listing these items in the technical products section of this document.

This document is organized by discipline, with each section containing the key products and technical assessments that will be used as a benchmark to determine acceptability of the Commercial Provider's technical standards and products.

Once the Commercial Provider and NASA have reached an agreement on an alternative technical standard, it will be added to the partnered set of standards for the CTS. Once this partnered set of standards is in place, it will be used in design evaluations in lieu of the standard called by CCT-REQ-1130. The content of this document will continue to be utilized as a reference for the types of products and analysis that are typically evaluated to establish technical adequacy for each discipline.

1.2 Scope

This document includes the criteria, expectations, and insight criteria that will be used in the evaluation of technical standards for launch vehicle, spacecraft, and ground system requirements identified by the CCP and the ISS Program for the CTS. The CTS refers to all assets and services necessary to meet the requirements of CCT-REQ-1130, including pre-flight planning, trajectory and abort analysis, ground processing and manufacturing, ground operations, mission control, training, launch control, launch, on-orbit operations, post-landing recovery operations, safety and mission assurance, and all other functions required for safe and successful human space flight missions. When elements of the CTS are technical or specific to a requirement, they will be called out; for example, the term *CTS spacecraft* will be used when the launch vehicle and ground elements are not specific to that portion of the design.

1.3 Precedence

In the event of a conflict between the text of this document and references cited herein (listed in Section 2.0), the text of this document takes precedence. The exception to this statement is for SSP 50808, which takes precedence during the arrival, docked, and departure operations. Nothing in this document supersedes applicable laws and regulations, unless a specific exemption has been obtained.

1.4 Delegation of Authority

This document was prepared by NASA's CCP, and will be maintained in accordance with standards for CCP documentation. The CCP is responsible for assuring the definition, control, implementation, and verification of the requirements identified in this document.

2.0 Documents

2.1 Requirements Applicability Matrix

The table below indicates where in this document a discipline has documented the evaluation that will be performed of the Commercial Provider's technical standard to determine if it meets the intent of the listed NASA or industry standard. This table also includes references to the appropriate section of CCT-REQ-1130 where that standard is specified.

Document Number	Revision	Title and CCT-REQ-1130 Requirement	CCT-STD-1140 Reference	CCT-STD-1140 Description
ANSI/ESD S20.20	Edition 07	<i>For the Development of an Electronic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices) (R.CTS.286)</i>	7.1.8.2 7.2.2	Avionics and Electrical Systems EEE Parts Management
FAA AC 20-136B	Rev. B	<i>Aircraft Electrical and Electronic System Lightning Protection (R.CTS.290)</i>	7.1.7.2	Avionics and Electrical Systems
GEIA-STD-0005-1	Baseline	<i>Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-Free Solder (R.CTS.277)</i>	7.1.5.2	Printed Wiring Boards Technical Assessment
GEIA-STD-0005-2	Baseline	<i>Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronics (R.CTS.278)</i>	7.2.2	EEE Parts Management
IEC 61000-4-2	Edition 2.0	<i>Electromagnetic Compatibility (EMC) Testing and Measurement Techniques-Electrostatic Discharge Immunity Test for Human Body Model (HBM) Subassemblies, Assemblies and Equipment Discharge Levels (R.CTS.371)</i>	7.1.8	Electrostatic Controls

Document Number	Revision	Title and CCT-REQ-1130 Requirement	CCT-STD-1140 Reference	CCT-STD-1140 Description
IPC J-STD-001E	Rev. E	<i>Requirements for Soldered Electrical and Electronic Assemblies</i> (R.CTS.275 and R.CTS.276)	7.1.5.2	Avionics and Electrical Systems
IPC J-STD-001ES Amendment 1		<i>Space Applications Electronic Hardware Addendum to J-STD-001E, Requirements for Soldered Electrical and Electronic Assemblies</i> (R.CTS.275 and R.CTS.276)	7.1.5.2	Avionics and Electrical Systems
IPC-2152	Baseline	<i>Standard for Determining Current Carrying Capacity in Printed Circuit Board Design</i> (R.CTS.270)	7.1.5.2	Avionics and Electrical Systems
IPC-2220 Series	2221: A 2222: A 2223: B 2224: BL 2225: BL 2226: BL	<i>Family of Printed Board Design Documents</i> (R.CTS.268)	7.1.5.2	Avionics and Electrical Systems
IPC-6010 Series	6011: BL 6012: C 6013: B 6015: BL 6016: BL 6017: BL 6018: A	<i>Family of Printed Board Performance Documents</i> (R.CTS.269)	7.1.5.2	Avionics and Electrical Systems
IPC-CM-770E	Rev. E (1/1/04)	<i>Component Mounting Guidelines for Printed Boards</i> (R.CTS.284)	7.1.5.2	Avionics and Electrical Systems
JSC 20793	Rev. C	<i>Crewed Space Vehicle Battery Safety Requirements</i> (R.CTS.282)	7.1.4	Avionics and Electrical Systems
JSC 62809	Rev. D	<i>Human-Rated Spacecraft Pyrotechnic Specification</i> (R.CTS.294)	7.1.3 7.3.2	Interconnecting Cable and Harnesses Pyrotechnics
JSC 65827	A	<i>Thermal Protection System Design Standard for Spacecraft</i> (R.CTS.293)	7.4.3.1	Thermal Protection Systems

Document Number	Revision	Title and CCT-REQ-1130 Requirement	CCT-STD-1140 Reference	CCT-STD-1140 Description
JSC 65828	Rev. B-1	<i>Structural Design Requirements and Factors of Safety for Spaceflight Hardware</i> (R.CTS.295)	7.4.3.1 7.4.1 7.5.2 7.6.2	Thermal Protection Systems Structures Fluid Systems Propulsion Systems
JSC 65829	A	<i>Loads and Structural Dynamics Requirements for Spaceflight Hardware</i> (R.CTS.297)	5.2.2 5.3.1 5.3.2 7.5.2 7.6.2	Structural Dynamics Int. Vehicle Dynamics Fluid Systems Propulsion Systems
JSC 65985	Rev. A	<i>Requirements for Human Spaceflight for the Trailing Deployable Aerodynamic Decelerator (TDAD)</i> (R.CTS.291)	7.7.2	Trailing Deployable Aerodynamic Decelerator
MIL-STD-461	Rev. F	<i>Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment</i> (R.CTS.287)	7.1.6.2	Avionics and Electrical Systems
MIL-STD-464	Rev. C	<i>Electromagnetic Environmental Effects Requirements for Systems</i> (R.CTS.288)	7.1.6.2	Avionics and Electrical Systems
MIL-STD-981	Rev. C	<i>Design, Manufacturing and Quality Standards for Custom Electromagnetic Devices for Space Applications</i> (R.CTS.289)	7.1.6.2	Avionics and Electrical Systems
MSFC-DWG-20M02540	E (1/15/92)	<i>Assessment of Flexible Lines for Flow-Induced Vibration</i> (R.CTS.303)	7.5.3	Fluid Systems
MSFC-SPEC-626	Basic (5/11/90)	<i>Test Control Document for Assessment of Flexible Lines for Flow Induced Vibration</i> (V.CTS.303)	7.5.3	Fluid Systems
NASA-STD-4003A	A	<i>Electrical Bonding For NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment</i> (R.CTS.281)	7.1.9.1	Avionics and Electrical Systems

Document Number	Revision	Title and CCT-REQ-1130 Requirement	CCT-STD-1140 Reference	CCT-STD-1140 Description
NASA-STD-4005	Baseline	<i>Low Earth Orbit Spacecraft Charging Design Standard</i> (R.CTS.285)	7.1.10	Avionics and Electrical Systems
NASA-STD-5012	Baseline	<i>Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines</i> (R.CTS.304)	7.4 7.6.2	Structures Propulsion Systems
NASA-STD-5017	Baseline	<i>Design and Development Requirements for Mechanisms</i> (R.CTS.292)	7.3 7.5.2	Mechanisms Fluid Systems
NASA-STD-5018	Baseline	<i>Strength Design and Verification Criteria for Glass, Ceramics, and Windows in Human Spaceflight Applications</i> (R.CTS.296)	7.4	Structures
NASA-STD-5019	Baseline	<i>Fracture Control Requirements for Space Flight</i> (R.CTS.307)	7.4 7.5.2 7.6.2 8.1	Structures Fluid Systems Propulsion Systems Fracture Control
NASA-STD-5020	BL (3/12/12)	<i>Requirements for Threaded Fastening Systems in Spaceflight Hardware</i> (R.CTS.298)	7.4	Structures
NASA-STD-6016	Baseline	<i>Standard Materials and Processes Requirements for Spacecraft</i> (R.CTS.260)	7.4.4 7.5.1 7.6.2 8.2	Structures Fluids Propulsion TDAD Materials and Processes
NASA-STD-7009		<i>Standard for Models and Simulations</i>	5.1.1 5.2.3 9.1.3	Models and Simulations Structures Software
NASA-STD-8739.1	Rev. A, change 2	<i>Workmanship Standard for Polymeric Application on Electronic Assemblies Wiring Boards and Electronic Assemblies</i> (R.CTS.274 and R.CTS.283)	7.1.5.2	Avionics and Electrical Systems

Document Number	Revision	Title and CCT-REQ-1130 Requirement	CCT-STD-1140 Reference	CCT-STD-1140 Description
NASA-STD-8739.4	Rev. R, change 6	<i>Crimping, Interconnecting Cables, Harnesses, and Wiring</i> (R.CTS.313 and R.CTS.279)	7.1.3	Avionics and Electrical Systems
NASA-STD-8739.5	Rev. R, change 2	<i>Fiber Optic Terminations, Cable Assemblies, and Installation</i> (R.CTS.273)	7.1.3	Avionics and Electrical Systems
NPR 7150.2A	Rev. A (11/19/09)	<i>NASA Software Engineering Requirements</i> (R.CTS.262)	9.1	Flight and Ground Software
SAE ARP 5412A	Rev. A	<i>Aircraft Lightning Environment and Related Test Waveforms</i> (R.CTS.290)	7.1.7.2	Avionics and Electrical Systems
SAE ARP 5414A	Rev. A	<i>Aircraft Lightning Zoning</i> (R.CTS.290)	7.1.7.2	Avionics and Electrical Systems
SAE ARP 5577	Basic	<i>Aircraft Lightning Direct Effects Certification</i> (R.CTS.290)	7.1.7.2	Avionics and Electrical Systems
SMC Standard SMC-S-016 (2008)		<i>Test Requirements for Launch, Upper-Stage, and Space Vehicles</i> (R.CTS.315)	5.6.2 7.1.2 7.3.1.2 7.5.2 7.6.2	Thermal Control Analysis Avionics Mechanisms Fluid Systems Propulsion Systems
SMC Standard SMC-S-010	Baseline	<i>Space and Missile Systems Center Standard, Parts, Materials, and Processes Technical Requirements for Space and Launch Vehicles</i> (R.CTS.319)	7.2.1	EEE Parts Management

2.2 Reference Documents

This section provides a list of technical and manufacturing standards that can be used as references during the launch vehicle, spacecraft, and ground system design activities. These references are not part of the formal requirements levied via CCT-REQ-1130.

Document	Revision	Title
15 CFR Part 287		<i>Guidance on Federal Conformity Assessment</i>
AE9/AP9		<i>Trapped Energetic Electron and Proton Environments (NSSDC/SDC-A-R&S 76-06 and NSSDC WDC-A-R&S 91-24)</i>
AFFDL-TR-72-3		<i>Ringsail Parachute Design (Ewing)</i>
AFSCMAN 91-710		<i>Air Force Space Command Range Safety User Requirements</i>
AGARDograph No. 319		<i>Design and Testing of High-Performance Parachutes</i>
AGARDograph No. 295		<i>The Aerodynamics of Parachutes</i>
AIAA S-111-2005		<i>Qualification and Quality Requirements for Space Solar Cells</i>
AIAA S-112-2005		<i>Qualification and Quality Requirements for Space Solar Panels</i>
ANSI/AIAA S-102.2.4-2009		<i>Performance Based Product Failure Mode, Effects, and Criticality (FMECA) Requirements</i>
ANSI C63.16		<i>American National Standard Guide for Electrostatic Discharge Test Methodologies and Criteria for Electronic Equipment</i>
ARM-10		<i>Apollo Technical Manual - Reliability</i>
AS5553		<i>Counterfeit Electronic Parts; Avoidance, Detection, Mitigation, and Disposition</i>
AS9003		<i>Inspection and Test Quality System</i>
ASD-TR-61-579		<i>Performance of and Design Criteria for Deployable Aero Decelerators</i>
ASME Boiler and Pressure Vessel Code, Sections VIII Divisions 1, 2, and 3		
ASME Y14.5-2009		<i>Dimensioning and Tolerancing</i>
ASTM D6193		<i>Standard Practice for Stitches and Seams</i>
ASTM E1066-95		<i>Standard Test Method for Ammonia Colorimetric Leak Testing</i>
ASTM Manual 36		<i>Safe Use of Oxygen and Oxygen Systems: Guidelines for Oxygen System Design, Materials Selection, Operations, Storage, and Transportation</i>
AWS D1/D1.1M		<i>Structural Welding Code-Steel</i>
AWS D1.2/D1.2M		<i>Structural Welding Code-Aluminum</i>
CPIA Publication 655 (1997-01)		<i>Guidelines for Combustion Stability Specifications and Verification Procedures for Liquid Propellant Rocket Engines</i>
CREME96		<i>Cosmic Ray Effects on Microelectronics, single event upset environments. Do not use for electrons.</i>
CxP 70038		<i>Constellation Program Hazard Analyses Methodology</i>

Document	Revision	Title
CxP 70043		<i>Constellation Program Hardware Failure Modes and Effects Analysis and Critical Items List (FMEA/CIL) Methodology</i>
DNA-TR-84-140		<i>Satellite Hardness and Survivability; Testing Rationale for Electronic Upset and Burnout Effects</i>
DOD-STD-2167A		<i>Defense Systems Software Development</i>
DOT/FAA/AR-MMPDS-01		<i>Metallic Materials Properties Development and Standardization</i>
E. Normand & T.J. Baker, 1993		<i>“Altitude and Latitude Variations in Avionics SEU and Atmospheric Neutron Flux” IEEE Transactions On Nuclear Science, Vol. 40, No. 6, December 1993</i>
Edwards, Normand & Dyer, 2004		<i>“Technical Standard for Atmospheric Radiation Single Event Effects, (SEE) on Avionics Electronics” 0-7803-8697-3/04/\$20.00 ©2004 IEEE</i>
Earth-GRAM 2010		<i>Global Reference Atmosphere Model (available from EV44, MSFC)</i>
EIA/IEEE J-STD-016-1995		<i>Standard for Information Technology Software Life-Cycle Processes Software Development Acquirer-Supplier Agreement</i>
Emission of Solar Protons		<i>Solar proton event, galactic cosmic ray environments, geomagnetic shielding</i>
FED-STD-209E		<i>Clean Room and Work Station Requirements, Controlled Environments</i>
GER-12616		<i>State-of-the-Art Study for High-speed Deceleration and Stabilization Devices</i>
GIDEP S0300-BT-PRO-010		<i>Government-Industry Data Exchange (GIDEP) Operations Manual</i>
GIDEP S0300-BU-GYD-010		<i>Government-Industry Data Exchange (GIDEP) Requirements Guide</i>
GSFC-STD-1000		<i>Goddard Space Flight Center Rules for the Design, Development, Verification, and Operation of Flight Systems</i>
IEEE 730-2002		<i>Institute of Electrical and Electronic Engineers (IEEE) Standard for Software Quality Assurance Plans</i>
IEEE STD C62.38		<i>IEEE Guide on ESD: ESD Withstand Capability Evaluation Methods (for Electronic Equipment Subassemblies)</i>
IEST-STD-CC1246D		<i>Product Cleanliness Levels and Contamination Control</i>
International Geomagnetic		<i>Terrestrial magnetic field Reference Field</i>
International Reference Ionosphere		<i>Cold low Earth orbit plasma environments Ionosphere</i>
ISO 14644		<i>Cleanroom Standards</i>
ISO 9001		<i>Quality Management Systems Requirements</i>
Jacchia-Bowman	2008	<i>Thermosphere drag (Available within Earth-GRAM 2010)</i>
JPR 8080.5		<i>JSC Design and Procedural Standards</i>

Document	Revision	Title
JSC 25863B		<i>Fracture Control Plan for JSC Space-Flight Hardware</i>
JSC EA3-10-015		<i>Deployable Aerodynamic Decelerator Requirements for Human Space Flight (3.9.9)</i>
JSSG-2010-12		<i>Crew Systems Deployable Aerodynamic Decelerator (DAD) Systems Handbook</i>
King 1972 SPE Model		<i>Crew Dose for Exposure to Solar Particle Event, Not Recommended for Avionics Applications (Journal of Spacecraft and Rockets, 11, 401, 1974)</i>
KSC-DE-512-SM		<i>Facility, System, and Equipment General Design Requirements</i>
KSC-NE-9439		<i>KSC Design Engineering Handbook for Design and Development of Ground Systems</i>
KSC-STD-Z-0006		<i>Standard for Design of Hypergolic Propellants Ground Support Equipment</i>
MEM		<i>Meteoroid Engineering Model (available from EV44, MSFC)</i>
MIL-A-83577B		<i>Assemblies, Moving Mechanical, For Space and Launch Vehicles, General Specification for</i>
MIL-C-5541		<i>Chemical Conversion Coatings on Aluminum and Aluminum Alloys</i>
MIL-DTL-38999	Rev. L	<i>General Specification for Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts</i>
MIL-H-7195		<i>General Specification for Parachute Hardware</i>
MIL-HDBK-17/1		<i>Composite Materials Handbook</i>
MIL-HDBK-340A		<i>Volume II Test Requirements for Launch, Upper Stage and Space Vehicles: Application Guidelines</i>
MIL-HDBK-5H		<i>Metallic Materials and Elements for Aerospace Vehicle Structures</i>
MIL-HDBK-83578		<i>Criteria for Explosive Systems and Devices Used on Space Vehicles</i>
MIL-PRF-27401C		<i>Propellant Pressurizing Agent, Nitrogen</i>
MIL-STD-1246C		<i>Product Cleanliness Levels and Contamination Control Program</i>
MIL-STD-129		<i>Marking for Shipment and Storage</i>
MIL-STD-1522A		<i>Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems</i>
MIL-STD-1546		<i>Parts, Materials, and Process Program Requirements</i>
MIL-STD-1576		<i>Electroexplosive Device Test Methods</i>
MIL-STD-1833		<i>Test Requirements for Ground Equipment and Associated Computer Software Supporting Space Vehicles</i>
MIL-STD-1472	Rev. G	<i>Department of Defense Design Criteria Standard Human Engineering</i>
MIL-STD-810G		<i>Environmental Test Methods and Engineering Guidelines</i>
MIL-STD-882		<i>Standard Practice for System Safety</i>
MIL-STD-1553		<i>Military Standard: Aircraft Internal Time Division Command/Response Multiplex Data Bus</i>
MSFC-HDBK-505	Rev. B	<i>Structural Strength Program Requirements</i>

Document	Revision	Title
MSFC-SPEC-164	Rev. C	<i>Specification for Cleanliness of Components for Use in Oxygen, Fuel and Pneumatic Systems</i>
MSFC-STD-156		<i>Standard for Riveting, Fabrication, and Inspection</i>
MSFC-STD-481		<i>Standard Radiographic Inspection and Acceptance Standards for Fusion-Welded Joints in Stainless and Heat-Resistant Steel</i>
MSFC-STD-3012		<i>EEE Parts Management and Control for MSFC Space Flight Hardware</i>
MSFC-STD-3535	Baseline	<i>Standard for Propellants and Pressurants Used for Test and Test Support Activities at SSC and MSFC</i>
MSIS-86		<i>Atomic oxygen (Available within GRAM 2010)</i>
MVWP		<i>Monthly Vector Wind Model (See NASA/TM 2008-215633)</i>
NASA TN D-5968		<i>An Investigation of the Initial Century Series Ringsail Parachute</i>
NASA-CR-131200		<i>Apollo Parachute Landing System (Knacke)</i>
NASA-HDBK-7005		<i>Dynamic Environmental Criteria</i>
NASA-HDBK-5010	Baseline	<i>Fracture Control Implementation Handbook for Payloads, Experiments, and Similar Hardware</i>
NASA SP-106		<i>The Dynamic Behavior of Liquids</i>
NASA SP-8057	Revised 1972	<i>Structural Design Criteria Applicable to a Space Shuttle</i>
NASA SP-8060		<i>Compartment Venting, NASA Space Vehicle Design Criteria</i>
NASA-STD-2202-93		<i>Software Formal Inspections Standard</i>
NASA-STD-3001	Volume 1	<i>NASA Space Flight Human System Standard Volume 1: Crew Health</i>
NASA-STD-3001	Volume 2	<i>NASA Space Flight Human System Standard Volume 2: Human Factors, Habitability, and Environmental Health</i>
NASA-STD-5001	Rev. A	<i>Structural Design and Test Factors of Safety for Spacecraft Hardware</i>
NASA-STD-5002		<i>Load Analyses of Spacecraft and Payloads</i>
NASA-STD-7009		<i>Standard for Models and Simulations</i>
NASA-STD-8719.9		<i>Standard for Lifting Devices and Equipment</i>
NASA/TM-2001-211221		<i>Guidelines for the Selection of Near-Earth Thermal Environment Parameters for Spacecraft Design.</i>
NASA-TM-2008-215106		<i>GN&C Engineering Best Practices for Human-Rated Spacecraft Systems</i>
NASA/TM-2008-215633		<i>Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development</i>
NASA-TM-X-74335		<i>U.S. Standard Atmosphere, 1976</i>
NASA/SP-2010-3407	Baseline	<i>Human Integration Design Handbook</i>
NESC-RP-06-108/05-173-E		<i>Design, Development Test and Evaluation (DDT&E) Considerations for Safe and Reliable Human-Rated Spacecraft Systems</i>

Document	Revision	Title
No Number		<i>NASA Fault Tree Handbook with Aerospace Applications, Version 1.1, dated August 2002</i>
NPD 8700.1	Rev. E	<i>NASA Policy for Safety and Mission Success</i>
NPD 8700.3	Rev. B	<i>Safety and Mission Assurance (S&MA) Policy for NASA Spacecraft, Instruments, and Launch Services</i>
NPD 8720.1	Rev. C	<i>NASA Reliability and Maintainability (R&M) Program Policy</i>
NPD 8730.1	Rev. C	<i>Metrology and Calibration</i>
NPR 2810.1A	Rev. A	<i>Security of Information Technology</i>
NPR 6000.1		<i>Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment and Associated Components</i>
NPR 7120.5	Rev. D	<i>NASA Space Flight Program and Project Management Requirements</i>
NPR 7123.1	Rev. A	<i>NASA Systems Engineering Processes and Requirements</i>
NPR 8705.2B	Rev. B	<i>NASA Human-Rating Requirements for Space Systems</i>
NPR 8715.3	Rev. C	<i>NASA General Safety Program Requirements</i>
NPR 8735.1	Rev. B	<i>Procedures for Exchanging Parts, Materials, and Safety Problem Data Utilizing the Government-Industry Data Exchange Program (GIDEP) and NASA Advisories</i>
NPR 8735.2		<i>Management of Government Safety and Mission Assurance Surveillance Functions for NASA Contracts</i>
NWC TP 6575		<i>Parachute Recovery Systems Design Manual</i>
O'Neill-Badhwar GCR Model	2006	<i>O'Neill, P.M., Badhwar – O'Neill Galactic Cosmic Ray Model Update Based on Advanced Composition Explorer (ACE) Energy Spectra from 1997 to Present, Advances in Space Research, Vol. 37, pp 1727-1733, 2006</i>
ORDEM 3.0		<i>Orbital Debris Engineering Model from the JSC Orbital Debris Program Office</i>
RTCA DO-160E	Rev. E	<i>Environmental Conditions and Test Procedures for Airborne Equipment (Sections 22 and 23)</i>
SAE ARP 4761		<i>Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment</i>
SAE ARP 5416		<i>Aircraft Lightning Test Methods</i>
SAE-AS-1098	Rev. B	<i>Fitting End, Flared Tube, for Seal Ring, Standard Dimensions for, Design Standard</i>
SAE-AS-5440	Rev. A	<i>Hydraulic Systems, Military Aircraft, Design and Installation Requirements for</i>
Solar Irradiance Platform		<i>UV-EUV</i>
SSP 30558		<i>Fracture Control Requirements for Space Station</i>
SWRI Publication by Dodge	2000	<i>The New 'Dynamic Behavior of Liquids in Moving Containers</i>

3.0 Background

This document has been divided into several disciplines that are traditionally part of every human-rated space flight program. Each discipline section outlines the products and processes that are typically part of, and critical to, the success of a highly complex space transportation system. The products and processes generally focus on ensuring that a comprehensive approach is taken that is consistent with the safety requirements of a human-rated system.

Each section starts with a general narrative and has three subsections as defined below:

Technical Products

A description of discipline specific artifacts that typically support the development effort and are used to substantiate the adequacy of required Commercial Provider standards called out in Section 3.9 of CCT-REQ-1130 and/or are considered a crucial product in the review of the Commercial Provider's development effort. Acceptable governing standards and processes should call for the creation of these products in some form by the Commercial Provider. The Commercial Provider may use internal processes, formats, standards, and specifications for the development of these products.

There are several technical products that will be reviewed by most of the disciplines, systems, and subsystems for substantiating the standards and processes used for designing, developing, and certifying the CTS. Examples of such artifacts are listed below. This list is not meant to be a formal list of deliverables, but is meant to convey to the Commercial Provider the typical artifacts that should be reviewed to evaluate proposed Commercial Provider designs, standards, and processes.

- Development testing results (components, subsystem, system-level)
- Design certification/qualification test results (components, subsystem, system-level)
- Design certification/qualification review data package (components, subsystem, system-level)
- Acceptance criteria and procedure (system, subsystem, and component)
- Critical design review data packages
- Failure modes and effects analysis (FMEA) results
- Reliability predictions and basis for predictions documentation
- Hardware specifications (components, subsystem, system-level)
- Interface control documentation
- Drawings or equivalent solid models
- System connectivity and functional schematics
- Structural and fatigue analysis reports
- Material properties
- Materials acceptance/process control plan
- Avionics functional decomposition (components, subsystem, system-level)
- Sensors/instrumentation specification and function
- Software testing and verification results
- Engineering change proposals process, material discrepancy report system, and non-conformance reporting (components, subsystem, system-level)
- Hardware acceptance test criteria (components, subsystem, system-level)

Technical Assessment

This section has a description of the technical criteria that will be used in assessing the adequacy of the Commercial Provider's standards and reflects NASA's areas of emphasis in reviewing the Commercial Provider's design. This section will describe areas of emphasis from relevant NASA and industry standards for determining if the Commercial Provider's proposed design standards meet the intent of the design standards required by Section 3.9 of CCT-REQ-1130.

This section may also describe the insight criteria that will be used to evaluate the adequacy of the Commercial Provider's design, beginning with the evaluation of the Commercial Provider's standards and processes.

References (Optional)

This section has a discipline specific list of relevant NASA and industry specifications, standards, and processes that NASA currently uses to design, develop, and certify human space flight programs. Discipline sections may include this information in order to provide the Commercial Provider a complete listing of all available technical standards that may be used for design, development, test, and evaluation of a CTS. The Commercial Provider does not need to meet the intent of these standards unless they are specified as such in CCT-REQ-1130 and Table 2.1 of this document.

4.0 Safety and Mission Assurance

Safety and Mission Assurance (S&MA) encompasses the traditional disciplines of safety, reliability, maintainability, and quality assurance. This section provides guidance on the S&MA processes outlined in CCT-PLN-1100 and the requirements contained in CCT-REQ-1130. Human certification relies heavily on the technical activities and products described in the following S&MA sections and in CCT-PLN-1120. Other sections of this document, such as design, test, production, and workmanship standards, are also of interest by S&MA, but are handled by other technical management. The following sections describe the CCP approach to the evaluation of the technical standards called in CCT-REQ-1130 for S&MA.

4.1 Safety Standard for Explosives, Propellants, and Pyrotechnics

4.1.1 Safety Standard for Explosives, Propellants, and Pyrotechnics Technical Assessment

An Explosive Safety Plan should summarize the approach, for vehicle, launch site, and any other locations where NASA personnel are operating. The Explosive Safety Plan should address:

- Operational explosives limits.
- Personnel limits.
- Limit control.
- Identification of live and inert hardware.
- Security and training.
- Operating procedures.
- Explosion hazards and exposure risk management.

4.2 Safe Use of Laser Diode and LED Sources

4.2.1 Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources Technical Products

An Optical Fiber and Laser Fiode Utilization Plan should guide the design and use of these devices and should include, at a minimum:

- A listing of all laser devices used during planned ground and flight operations where NASA personnel will be potentially exposed to laser sources.
- The laser specification (e.g., wavelength, power output for nominal and worst case failure scenario, etc.).
- Operational procedures, including hazard controls.

4.2.2 Reserved

5.0 Integrated Analysis

All integrated analyses should include the following important attributes. Documentation should demonstrate that these elements have been captured.

- All vehicle and environmental models use, address, and sufficiently account for uncertainties inherent in modeling and environment characterization.
- Interactions and relationships between subsystems are identified and defined.
- The operations team for the vehicle/mission is involved with the design teams from the earliest design phases to provide input to the design teams and to understand design decisions made.
- The coordinate frames and the system of units (and associated conversion factors) that are to be employed are documented and compliance is rigorously enforced.
- An integrated vehicle analysis that accounts for subsystem interactions and overall mission design.

5.1 Models and Simulations

Many of the system sections of this document identify specific subsets of the products and technical assessments expected for modeling and simulation. Although these subsets are of especial interest to the specific system, it is noted that the modeling and simulation products and technical assessments identified in this section are expected for all applicable models and simulations (M&S), regardless of if they are specifically identified under those system sections.

Documentation related to any models or simulations whose analysis results are used to make critical decisions regarding design, development, manufacturing, and ground or flight operations that may impact human safety or Program-defined mission success criteria will be reviewed. Of particular interest are the methods and procedures used a) for determining (through risk assessments) which software models and simulations influence critical decisions and b) for assessing and communicating the credibility of model/simulation analysis results based on factors such as verification, validation, input pedigree, results uncertainty quantification, results robustness, use history, qualifications of applicable personnel, and M&S management.

At a minimum, it is expected that all M&S used for making critical decisions are identified. In addition, for those M&S that are used to make critical decisions, it is expected that the credibility assessment factors identified in the previous paragraph be communicated in conjunction with the specific results provided from those M&S. Specific M&S analysis results include the following:

- Results estimate (based on an appropriately verified and validated model with input data of appropriate pedigree).
- Quantitative statement of uncertainty in the results (results uncertainty quantification).
- Caveats that accompany the results, e.g., errors, warnings, etc. (results robustness, use history, personnel qualifications, and/or M&S management issues).
- An understanding of the associated risks (results of risk assessments).

Appendix C provides examples of how M&S used for making critical decisions can be identified, along with an example method for communicating the key credibility and risk assessment factors to the people making decisions influenced by the analysis results produced by these M&S.

5.1.1 Models and Simulations References

Document Number	Revision	Title
NASA-STD-7009		<i>Standard for Models and Simulations</i>

5.2 Structural Dynamics Analysis, Loads, and Models

The purpose of analyses performed to predict loads and structural dynamic responses is to evaluate events which occur over the course of a vehicle's mission profile and ensure that bounding design conditions are defined. Design-to loading conditions must be identified with sufficient accuracy and statistical likelihood to preclude structural failure over the vehicle design and operational life-cycle. Key to this effort are the fidelity of the characterizations of the environments and loading sources to which a structure will be exposed and of models used for prediction of dynamic responses over the entire spectrum of excitation frequencies.

5.2.1 Structural Dynamics Analysis, Loads, and Models Technical Products

Products to substantiate adequacy of loads and dynamic response predictions typically include both models and analysis reports. These reports should document analyses (e.g., loads, vibration, vibroacoustic, etc.) conducted on the vehicle, including its systems, subsystems, and components, to generate data used to calculate stresses and/or to identify operational limits and restrictions. Analysis documentation/reports should include assumptions, boundary conditions, applied environments (natural and induced), and forcing functions for response analyses, rationale, models, and appropriate results. Appropriate results include all significant loads encountered during vehicle service life, from manufacturing to the end of service, and vibroacoustic environments to be used for range safety, transportation, hardware qualification, and workmanship screening. Additional products, including failsafe flight data (i.e., black box or telemetry) and system models, will be required for reconstruction following major anomalies, failures, or aborts.

Analysis reports should also include documentation of all math models used for loads and dynamic response analyses. Model verification and validation with standard methods, including use of multiple independent models, should be well documented with the model validation data accessible and traceable to the appropriate model. Model descriptions should indicate pertinent modeling parameters, model display, material properties used, and type of model. A full description of the tests to be used, or which have been used, to validate the models is expected as part of the Structural Verification Plan (SVP).

5.2.2 Structural Dynamics Analyses, Loads, and Models Technical Assessment

NASA has a strong expectation that any alternate standard for structural dynamics analysis, loads development, and models would include, at minimum:

- Performance of a minimum of two load cycles, including a preliminary design cycle and a verification analysis cycle.
- Use of validated models in the verification analysis cycle.
- Use of validated environments and forcing functions in the verification analysis cycle.
- Documentation of all models, environments, and forcing functions developed for assessment of all mission phases and all associated output requests, load indicators, load indicator redlines, and output transformation matrices.

Review of the structural dynamic analyses, loads, and models will determine if a standard meets the intent of JSC 65829, *Loads and Structural Dynamics Requirements for Space Flight Hardware*. Review will place specific emphasis on:

- Model validation.
- Dynamic event selection and associated forcing function development.
- Treatment of combination of effects of simultaneous or event-consistent load sources.
- Treatment of combination of effects of quasi-static, low-frequency transient, and random loading environments.
- Vehicle natural and induced environments used in dynamic response prediction.
- Validation of induced environments used in dynamic response prediction.
- Expected sources of data for anomaly/failure investigation and resolution.
- Engine margin validation.

Specific goals of this review are to:

- Verify that the process/approach used to model the dynamics, including frequencies, modes, and damping, is complete, accurate, and incorporates appropriate uncertainty factors.
- Verify predicted responses for critical mission events via NASA Independent Verification and Validation (IV&V) coupled loads analysis using contractor models and forcing functions.
- Validate that frequencies and modes of the dynamic models are traceable to ground testing.
- Validate the induced crew cabin internal environments (i.e., acceleration, vibration, acoustic, and shock) to which the flight crew will be exposed.
- Validate flight environments and flight loads.
- Validate the self-induced environments and loads to which the engine(s) will be exposed.
- Validate the engine environments and loads to which the vehicle components will be exposed during all phases of main propulsion system (MPS) development, green run, and flight, in which the engine and vehicle are hot-fire tested as a system, such as during stage green-run or MPS development tests.

Final determination that the vehicle, element (stage), system, and/or components are qualified with respect to dynamic loads and environments will be based on review of:

- Qualification/acceptance documentation, including associated test documents and data.
- Vibroacoustic and shock environment derivation analyses, including validating test data and analyses.
- Forcing functions for all significant flight events, including derivation methodologies and supporting flight/ground test data and analyses used.
- Mapping of environments to elements, system, or component locations.
- Performance requirements and substantiating ground and flight test data.

5.2.3 Structural Dynamics Analyses, Loads, and Models References

Document Number	Revision	Title
NASA-STD-5002		<i>Load Analyses of Spacecraft and Payloads</i>
NASA-HDBK-7005		<i>Dynamic Environmental Criteria</i>
NASA-STD-7009		<i>Standard for Models and Simulations</i>

5.3 Integrated Vehicle Dynamics Analysis

5.3.1 Integrated Vehicle Dynamics Technical Products

During atmospheric and exoatmospheric flight, space flight vehicles are subject to numerous sets of circumstances where the possibility exists for coupling between the vehicle dynamic response and either external or self-induced excitation and/or operation of vehicle subsystems. Among these are static and dynamic aeroelastic instabilities, pogo, control/structure interaction, etc. Generally, flight vehicles cannot be designed to withstand these phenomena. Rather, analyses are performed to demonstrate margins with respect to onset of these effects (divergence, flutter, panel flutter, control reversal, control/structure interaction, pogo stability, etc.).

Section 6 in JSC 65829, *Loads and Structural Dynamics Requirements for Space Flight Hardware* defines requirements covering coupling phenomena or other interaction between structural dynamics and aerodynamic environments, vehicle control systems, or propulsion system elements. Such requirements encompass multiple technical disciplines, including structures, propulsion, aerodynamic, and control system architecture. It is expected that Commercial Providers will have existing standards and design practices to address and mitigate these dynamic coupling phenomena. In this event, the adequacy of such standards/practices is subject to review with respect to the requirements in JSC 65829.

Products to substantiate adequacy of integrated vehicle dynamics consideration should consist of analysis models and reports documenting analyses conducted on the vehicle, its systems, subsystems, and components to generate data used to establish margins with respect to the various coupling phenomena. Analysis documentation/reports should include assumptions, boundary conditions, applied environments (natural and induced) and forcing functions for response analyses, rationale, models, and appropriate results.

Analysis reports should also include documentation of all math models used for the analyses. Verification and correlation of models should be well documented with the model validation data accessible and traceable to the appropriate model. Model descriptions should indicate pertinent modeling parameters, model display, material properties used, and type of model. A full description of the tests to be used, or which have been used, to validate the models is expected as part of the SVP.

5.3.2 Integrated Vehicle Dynamics Technical Assessment

Review and assessment of integrated dynamics analyses will determine if a Commercial Provider's standards meet the intent of JSC 65829, *Loads and Structural Dynamics Requirements for Space Flight Hardware*. Review and assessment will place specific emphasis on:

- Validation of the process/approach used to model the dynamics, including frequencies, modes, and damping.
- Validation of the models used in performing the analyses.
- Validation of induced environments used in dynamic response prediction.
- Demonstration of required margins for static and dynamic aeroelastic effects (e.g., divergence, flutter, panel flutter, control surface buzz, control reversal, etc.).
- Characterization of stall flutter and verification of positive structural/control margins at high angle-of-attack (where applicable to vehicle design).
- Demonstration of required control system stability margins with respect to vehicle flexible dynamics.

- Results and margins from pogo stability analysis.
- Evaluation of propulsion thrust oscillation, if any, on the integrated vehicle stack.
- Predictions of vehicle slosh mode frequencies and damping.
- Demonstration of required control system stability margins with respect to vehicle slosh modes.
- Mitigation of flow-induced vibration in flex hoses and bellows.
- Availability of data and models for anomaly/failure investigation and resolution.

5.3.3 Integrated Vehicle Dynamics References

Document Number	Revision	Title
NASA SP-8057 (revised 1972)		Structural Design Criteria Applicable to a Space Shuttle
NASA-HDBK-7005		Dynamic Environmental Criteria

5.4 Flight Mechanics and GN&C

The purpose of analyses and tests performed in this area is to demonstrate that vehicle flight will be safe and successful with respect to these discipline areas through analysis. Key to this effort is correct modeling of the various vehicle systems, along with their uncertainties, and rigorous verification.

5.4.1 Flight Mechanics and GN&C Technical Products

Products to substantiate adequacy of flight mechanics and guidance, navigation, and control (GN&C) analysis and test typically include both models and analysis, as well as test reports. Analysis reports should include sufficient information to demonstrate that the appropriate amount of rigorous analysis has been conducted and provide the detail necessary for the evaluator to reach the same conclusions. Analysis reports should also include documentation of all math models and simulations used. Verification and correlation of models and simulations should be well documented with the model validation data accessible and traceable to the appropriate model. Likewise, test reports should document the appropriate testing sufficient for the reader to verify that the tests were appropriately conducted and that the results were successful.

5.4.2 Flight Mechanics and GN&C Technical Assessment

NASA has a strong expectation that any Commercial Provider flight mechanics and GN&C analysis for human-rated systems would include, at minimum:

- High-fidelity 6 degree-of-freedom time domain simulations, including dispersions and failure modes are performed such that:
 - Dispersion analysis demonstrates that the mission success, safety, and performance requirements are satisfied.
 - Stress cases are conducted to demonstrate system robustness.
 - Propellant margins are shown to be adequate.
- Flight control designs meeting stability and controllability criteria:
 - Maintain rigid body margins of 6db gain and 30 degrees phase for non-dispersed conditions and maintain margins of 3db gain and 20 degrees phase for dispersed conditions.
 - Maintain flex body margins of 6db gain and 30 degrees phase for dispersed conditions.
 - Maintain equivalent robustness measures for non-classical design approaches (i.e., non-linear).

- Flight control system stability analysis determining what, if any, slosh damping characteristics are required to maintain vehicle or spacecraft stability.
- The control actuation system has the sufficient control authority required for known disturbances and dispersions.
- The dynamics in ALL flight phases are analyzed (e.g., aerodynamics, flexibility, damping, gyrodynamic, plume impingement, moving mechanical assemblies, fluid motion, changes in mass properties, tail-wags-dog, etc.).
- The GN&C subsystem should adhere to the “Test Like You Fly” philosophy.

NASA has a strong expectation that testing for human-rated systems would include items, such as the following:

- All heritage hardware/software in the CTS subsystem architecture is evaluated and tested to determine its viability for use in a human-rated system with while taking into account the differences in build, flight configuration, mission application, flight environment, or design/operations teams required to achieve human-rating.
- The system adheres to the “Test Like You Fly” philosophy such that it is tested and flown in the same configuration and operational modes.
- The vehicle subsystem models used in simulations are validated by test to the maximum extent possible.
- Verification of subsystem design models and simulations should be performed prior to human flight.
- All unexpected results or anomalies during hardware testing are explained and/or incorporated into the simulation math model.
- Hardware-in-the-Loop testing (that includes sufficient hardware to capture all critical subsystem interfaces) is conducted to verify proper and expected H/W and S/W interactions in all operational modes, during mode transitions, and all mission critical events, and including all software paths.
- End-to-end integrated flight HWIL simulation should be used for validating the software simulation for timing and communications models.
- A true end-to-end sensors-to-actuators polarity and coordinate systems test is conducted for all flight hardware/software configurations, including all flight harnesses/data paths, and resolving all test anomalies.
- Test reports should include analysis results performed in support of verification and validation of performance requirements.
- Flight tests are performed to verify and validate nominal and abort design and operations with flight-like hardware and software.
- Human-in-the-Loop testing to verify handling qualities during manual control of the spacecraft's flight path and attitude during all applicable phases where manual control is planned including ISS proximity operations.

5.4.3 Flight Mechanics and GN&C References

Document Number	Revision	Title
NASA-TM-2008-215106		GN&C Engineering Best Practices for Human-Rated Spacecraft Systems

5.5 Integrated Abort Analysis

The purpose of integrated abort analyses are to confirm that a robust abort capability exists across all mission phases, beginning with the timeframe that the crew ingresses the launch vehicle stack, all the way until the crew has successfully been recovered post-mission by the ground support team.

5.5.1 Integrated Abort Analysis Technical Products

Products to substantiate adequacy of abort design and operations typically include both models and analysis and test reports. Analysis reports should cover the full range of abort options from pre-launch through post-landing phases. Analysis reports should include sufficient information to demonstrate that the appropriate amount of rigorous analysis has been conducted and provide the detail necessary for the evaluator to reach the same conclusions. Analysis reports should also include documentation of all math models and simulations used. Verification and correlation of models should be well documented with the model validation data accessible and traceable to the appropriate model. Likewise, test reports should document the appropriate testing sufficient for the reader to verify that the tests were appropriately conducted and that the results were successful. Test reports should include analysis of abort flight test missions performed in support of verification and validation of abort capabilities. A full description of the tests to be used, or which have been used, to validate the models is expected as part of the SVP.

5.5.2 Integrated Abort Analysis Technical Assessment

NASA expects that the Commercial Provider will perform 3 DOF and 6 DOF statistical analyses using closed-loop GN&C simulation and including vehicle and environmental uncertainties, which address at least the following areas:

- Abort trigger settings, designed such that they will provide for both a low probability of false positive and a low probability of false negative.
- Identification of parameters or measurements used as abort trigger, and the process and rationale for their selection.
- Identification and simulation of ascent failure scenarios, conducted to ensure the ability of the crew module to depart the launch vehicle prior to reaching any vehicle and crew module limit loads or other “demise” criteria (in nearly all cases).
- Analysis of ascent abort operations and its interaction with pending flight termination commanding.
- Required abort success percentages are achieved at each moment in each flight phase.
- Appropriate sizing of discrete time steps for abort initiation within the larger time bins.
- Appropriate approach to modeling temporally overlapping failure modes.
- Appropriate approach to modeling temporally overlapping abort modes.
- Spacecraft touch down within safe landing and recovery areas.

The above analyses are conducted for probabilistic dispersed flight conditions and for probabilistic failure modes. During modeling of failures and subsequent abort, loss of control dynamic effects and blast and debris environments should be considered, along with launch abort vehicle stability and control and subsequent crew module flight.

5.6 Thermal Control Analysis and Models

The purpose of integrated thermal analyses is to demonstrate that the vehicle performs within allowable temperature limits for all flight phases (pre-launch, ascent, on-orbit, entry, and post-entry). Key to this effort is the use of integrated thermal math models of the vehicle, systems, subsystems, and components to determine the flight thermal environments and overall vehicle thermal performance. Analytical verification cycles would be expected early in the Program using a Design Reference Mission (DRM) design that reasonably encompasses most expected actual missions, as well as mission-specific analysis cycles, to capture vehicle modifications throughout its life-cycle and derive more nominal thermal expectations for any particular mission.

5.6.1 Thermal Control Analysis and Models Technical Products

Products to substantiate adequacy of overall integrated vehicle thermal response predictions include thermal math models and analysis reports. Analysis reports should include sufficient thermal performance information to assess and ensure thermal compliance for all mission phases (prelaunch, ascent, on-orbit, entry, and post-entry). These reports should document data used to assess thermal response of the integrated system, as well as to identify any mission operating thermal constraints. Analysis documentation/reports should include vehicle allowable temperature limits (operational, non-operational, safety), bounding thermal environment parameters (natural and induced), thermal DRM (vehicle attitudes/orientations and timeline durations), thermal design approach and description, and appropriate results. Analysis reports should also document predicted/measured thermal control heater duty cycles and identify thermal instrumentation locations.

Reports should include documentation of thermal math models (uncorrelated and correlated) used for thermal predictions. The use of uncorrelated models by Commercial Providers should carry sufficient thermal margin so as to accommodate the higher level of uncertainty associated with those models. Model descriptions should indicate thermo-physical and optical properties, thermal analysis margin, and uncertainties.

5.6.2 Thermal Control Analysis and Models Technical Assessment

NASA has an expectation that any Commercial Provider developed standards for integrated thermal control analysis and models would meet the intent of SMC-S-016, *Test Requirements for Launch, Upper Stage, and Space Vehicles*, and include, at minimum:

- Use of validated and correlated models in the verification analysis cycle.
- Performance of mission specific thermal assessments and verification, inclusive of nominal and off-nominal attitude timeline mission operational modes.
- Analyze vehicle thermal control function performance and define on-orbit thermal environments for integrated thermal analysis with the docked vehicle, including interfaces and critical locations, and identify significant thermal performance issues.
- Maintain configuration control of integrated thermal math models for defining natural and induced environments and performing integrated thermal analysis.

5.6.3 Thermal Control Analysis and Model References

Document Number	Revision	Title
SMC-S-016		<i>Test Requirements for Launch, Upper-Stage, and Space Vehicles</i>

5.7 Aerospace

Three major categories are involved in evaluating the performance and safety of aerospace related environments:

- The forces and moments on a vehicle during ascent and entry.
- The aerothermodynamic heating on a vehicle.
- The on-orbit plumes and their effect on surrounding objects.

The tools available to define these environments are wind tunnel testing, computational methods, engineering or analytical methods, and flight testing. Each of these environments has associated uncertainties and margins. The guidelines for determining the level of required fidelity for each of these categories is outlined below.

5.7.1 Aerodynamics

Requirements on aerodynamic environments can be divided into two categories: scope/coverage and fidelity/accuracy. Scope/coverage requirements are determined by the operation range of the vehicle, while fidelity/accuracy requirements are typically not levied directly on the aerodynamic database, rather the requirements and/or performance criteria of other disciplines (e.g., structures, GN&C, etc.) determine the fidelity needed for the aerodynamic environments. This indirect path leads to a set of derived requirements for the aerodynamics that are determined through an iterative multi-disciplinary analysis process targeting production of nominal aerodynamic environments with a level of uncertainty that allows other disciplines to meet requirements.

To enable a meaningful review of the aerodynamic environments, the Commercial Provider should provide an aerodynamic substantiation report which documents how the data for the database was acquired, what best practices and assumptions were used, how associated uncertainties and margins were developed and applied, evidence that the uncertainties are appropriate, and how verification and validation was applied to the overall process. The report should also demonstrate that the aerodynamic database provides sufficient coverage for the flight regime that the vehicle may encounter and that any reconstitution of the database to be incorporated into the flight dynamics simulations accurately reflects the aerodynamic database itself.

5.7.2 Aerothermal

The methodology for defining aerothermal design environments must be documented. Specifically, the approach used for defining the heat transfer, pressure loading, and shear stress caused by the flow around the vehicle must be defined, including: 1) nominal acreage heating to heat-load and heat-rate sensitive components, 2) specialized design environments for control surfaces, thermal barriers, protuberances, cavities, and jet interactions where appropriate, 3) modeling assumptions for laminar, transitional, and turbulent flow states, and 4) the uncertainties applied to such environments. The use of aerothermal environments as part of a larger thermal protection system margin policy should be presented.

To enable a meaningful review of the aerothermodynamic environments, the Commercial Provider should provide an aerothermodynamic substantiation report which documents how the data for the database was acquired, what best practices and assumptions were used, how associated uncertainties and margins were developed and applied, evidence that the uncertainties are appropriate, and how verification and validation was applied to the overall process. The report should also demonstrate that the aerothermodynamic database provides sufficient coverage for the flight regime that the vehicle may

encounter and that any reconstitution of the database into the thermal protection system design process accurately reflects the aerothermodynamic database itself.

5.7.3 On-Orbit Plumes

To ensure the safety of the ISS crew and the integrity of the ISS, vehicles which visit the ISS must be operated such that any plume impingement of the visiting vehicle to the ISS does not cause any adverse effects, such as excessive structural loads, excessive temperature rise, excessive contaminant deposition, or excessive surface erosion. Verification of this requirement will be performed by analysis.

Such analyses require the definition of the plume flow field environment, which may be in the form of either of an algebraic math model or tabular data for such quantities as dynamic pressure, velocity magnitude, and the distribution of non-gaseous effluents in the plume. The Commercial Provider providing crew transportation service are expected to provide either such an environment, or alternatively, the data for the vehicle's reaction control system thrusters, such as combustion chamber operating parameters, nozzle contour shape(s), engine thrust level(s), and engine mass flow rate(s). The latter alternative allows the Government to develop the required environments. The chosen alternative will be negotiated between NASA and the Commercial Provider.

These analyses also require data on the operation of the thruster during proximity operations for both nominal and off-nominal (including hardware failure and commanded abort) scenarios. The Commercial Provider is expected to provide a database of jet firing histories that give adequate coverage for such scenarios. Such a database should be developed using vehicle dynamics simulations, which include models that sufficiently represent the visiting vehicle's range of mass properties, the vehicle's sensors that provide position and attitude relative to the ISS, and the vehicle's control system logic/algorithms.

6.0 Ground Support Equipment

The purpose of this standard is to convey the minimum engineering best practices for the design of Ground Support Equipment (GSE). Additional engineering and safety practices for the design of GSE may be levied upon a Commercial Provider by the institution/site in which they are operating.

6.1 Ground Support Equipment

NASA has a strong expectation that a Commercial Provider's minimum engineering design best practices would address the items as referenced in NASA-STD-5005C, *Standard for the Design and Fabrication of Ground Support Equipment*.

6.1.1 Ground Support Equipment Design Technical Products

Products to convey the minimum engineering best practices when designing GSE that interfaces with flight hardware includes documentation that substantiates that each component has been adequately analyzed and/or tested.

6.1.2 Ground Support Equipment Design Technical Assessment

NASA has a strong expectation that a Commercial Provider's GSE documentation would include items, such as the following:

- Detailed stress analysis, including a summary of the margins of safety.
- Proof test demonstrations, including test reports.
- Component material certification.
- Critical weld inspections.
- Electrostatic discharge (ESD) compliance test reports.
- Electromagnetic compliance test reports.
- Electrical bonding compliance test reports.

6.1.3 Ground Systems Design References

Document Number	Revision	Title
NASA-STD-8719.9		<i>Standard for Lifting Devices and Equipment</i>
MSFC-STD-156		<i>Standard for Riveting, Fabrication, and Inspection</i>
MSFC-STD-481		<i>Standard Radiographic Inspection and Acceptance Standards for Fusion-Welded Joints in Stainless and Heat-Resistant Steel</i>
AWS D1/D1.1M		<i>Structural Welding Code-Steel</i>
AWS D1.2/D1.2M		<i>Structural Welding Code-Aluminum</i>
ASME Boiler and Pressure Vessel Code, Sections VIII Divisions 1, 2, and 3		
KSC-DE-512-SM		<i>Facility, System, and Equipment General Design Requirements</i>
KSC-NE-9439		<i>KSC Design Engineering Handbook for Design and Development of Ground Systems</i>
KSC-STD-Z-0006		<i>Standard for Design of Hypergolic Propellants Ground Support Equipment</i>

7.0 Launch Vehicle, Spacecraft, and Crew Systems Design

7.1 Avionics and Electrical Systems

7.1.1 Avionics Technical Products

The complexity of avionics equipment and the involvement of many independent organizations significantly add to the risk to performing a successful mission. Loss of mission due to an avionics failure proves to be very costly. Testing the avionics equipment extensively at several assembly levels (from units to the overall system) through the various Program verification phases (qualification, acceptance, pre-launch, and on-orbit) has been a cost effective way of further assuring successful equipment and operation.

In order to substantiate that the Commercial Provider meets the intent of standards required by CCT-REQ-1130, and to demonstrate that the system design meets applicable requirements for human-rating (which is capable of sustaining its operational role during the life-cycle), emphasis will be placed on the following, at a minimum:

- Subsystem and unit-level specifications.
- Electrical, Electronic, and Electromechanical (EEE) Parts Selection Plan and screening process.
- Materials Selection Plan for chassis (if different from that used for mechanical structure).
- Fasteners Selection Plan for chassis and assembly (if different from that used for mechanical structure).
- Unit interconnect drawings and schematics.
- Printed wiring board schematics and layout drawings.
- Box level assembly drawings.
- As-designed and as-built EEE parts list.
- As-designed and as-built mechanical parts list.
- Programmable device design and implementation processes.
- Programmable device design documentation (code and schematics).
- Programmable device test plans and data.
- Qualification plans, procedures, as-run data, and reports, including electromagnetic interference (EMI)/electromagnetic compatibility (EMC), ESD, and lightning transient testing.
- Worst case circuit analysis for each avionics unit.
- Avionics system analysis/test for throughput, noise/ripple on power, and electrical impedance/isolation for signals.
- Acceptance test plans, procedures, and as-run data.
- Avionics integrated system test plans, procedures, and as-run data.
- Electrical power quality requirements, including details on control of electrical faults.
- Electrical Power and Energy Plan.
- Sneak circuit analysis.

7.1.2 Avionics Technical Assessment

Review of acceptance and qualification data (test plans, procedures, and reports) verifies that the CTS (including refurbished or re-flown products) meets performance specifications, demonstrates acceptable quality and workmanship, and is ready to be committed to flight. Review and assessment of subsystems

and unit qualification and acceptance data will determine if a Commercial Provider's standards meet the intent of SMC-S-016, *Test Requirements for Launch, Upper-Stage, and Space Vehicles*.

For all existing avionics unit designs, qualification test reports/data will be reviewed to ensure testing was performed according to the Qualification Plan and to evaluate any anomalies identified during testing and the resolution of those anomalies. For all avionics unit designs, acceptance test plans and acceptance test reports/data will be reviewed prior to completion of vehicle integration to ensure testing was performed to the Acceptance Test Plan and all hardware passed acceptance testing. As-built design and manufacturing information will be made available for review for each avionics unit. Avionics systems-level designs, interfaces, and analyses will be reviewed for evaluation of proper avionics system function and adequate margins. All systems-level test plans and results, from a laboratory environment and from vehicle integration, will be made available for review to ensure testing was performed to the test plan and the avionics system passed all integrated testing. Test results will show that on-board computational capability is sufficient to execute all critical software operations at the appropriate frequency.

For new avionics unit designs, an assessment will be performed on all design documentation and component/materials selection plans to ensure specifications are met. Qualification plans will be evaluated to ensure units are tested to appropriate environmental levels, including EMI/EMC, in accordance with the Commercial Provider provided Environmental Electromagnetic Effects Control Plan. For new or modified avionics system-level designs, specifications will be evaluated to make sure avionics unit interfaces are verified to meet system interface requirements, and system-level test reports will be reviewed to ensure appropriate system performance. For all new or modified avionics unit designs and all new or modified avionics systems designs, the Commercial Provider will include avionics as part of the formal design review and certification process.

7.1.3 Interconnecting Cable and Harnesses

Considerable experience has been gained in the area of electrical wiring subsystems throughout NASA's history of human space flight. It is clear that there has to be sufficient processes and requirements for procuring components, implementing procedures for fabrication, installation, and testing, as well as associated training. Because of the large amount of wiring required and its impact on weight, volume, and the function of other subsystems, the importance of electrical wiring and connecting devices cannot be overemphasized.

7.1.3.1 Interconnecting Cable and Harness Technical Products

In order to substantiate that the Commercial Provider meets the intent of NASA-STD 8739.4, *Crimping, Interconnecting Cables, Harnesses, and Wiring*; NASA-STD-8739.5, *Fiber Optic Terminations, Cable Assemblies, and Installation*; and JSC 62809, *Human-Rated Spacecraft Pyrotechnic Specification*; and to certify the design, fabrication, and installation for human-rating, emphasis will be placed on the following, at a minimum:

- Voltage drop analysis.
- Routing and bend radius documentation showing circuit EMC.
- Comprehensive cabling bill of materials.
- Harness manufacturing process specification.
- Tool calibration and maintenance.
- Cable Qualification Test Plan.

- Harness Acceptance Test Plan.
- Personnel Training and Certification/Re-certification Plan.
- Installation Plan.
- Cable/Harness Test and Inspection Plan.
- Cable Maintenance Plan.
- Interconnectivity schematics.
- Wire lists.
- Installation drawings.

7.1.3.2 Interconnecting Cable and Harness Assembly Technical Assessment

Review and analysis of the electrical interconnect system design and verification process will determine if a Commercial Provider's standards meet the intent of the following:

- NASA-STD 8739.4, *Crimping, Interconnecting Cables, Harnesses, and Wiring*.
- NASA-STD-8739.5, *Fiber Optic Terminations, Cable Assemblies, and Installation*.
- JSC 62809, *Human-Rated Spacecraft Pyrotechnic Specification*.
- Verification that all mechanisms have a suitable operational range to encompass ground and flight environments, including static loading, dynamic loading, and thermal impacts.

A review of the documented methods and procedures proposed to incorporate requirements for interconnecting cable and harness assembly design, fabrication, installation, and associated testing will place emphasis on the following areas:

- Materials (e.g., conductor, insulation, connectors, etc.).
- Conductor stripping processes.
- Crimping processes and verifications.
- Separation of redundant harnesses/circuits.
- Electromagnetic interference/compatibility.
- Routing, support, and protection of harnesses for operating environments.
- Adjacent bent pin assessment.
- Red plague mitigation.

7.1.4 Crewed Vehicle Battery Safety

7.1.4.1 Crewed Vehicle Battery Safety Technical Products

In order to substantiate that the Commercial Provider meets the intent of JSC 20793, *Crewed Space Vehicle Battery Safety Requirements*, and to certify the design for human-rating, emphasis will be placed on the safety data package, which should include, at a minimum, the following:

- FMEA, including toxicity, materials, and off-gassing.
- Data that allows insight into the hazards (e.g., venting, fire, thermal runaway, etc.), as well as the controls for mitigation, along with the test methods used to verify the controls.
- Battery specifications, qualification, certification, lot, and flight acceptance test plans.
- Data from these tests.

7.1.4.2 Crewed Vehicle Battery Safety Technical Assessment

Review and analysis of the electrical crewed vehicle battery system design and verification process will determine if a Commercial Provider's standards meet the intent of JSC 20793, *Crewed Space Vehicle Battery Safety Requirements*.

Taking into account the battery's chemistry, launch environment, on-orbit usage, complexity, capacity, location, its propensity for venting, fire and thermal runaway, etc., evaluation criteria of the Crewed Vehicle Battery Safety Report/Plan/Test documentation submitted will place emphasis on the following areas:

- Fault tolerance to catastrophic failures.
- Incorporation and verification of hazard controls.
- Charging system implementation (if applicable) and safety.
- Mission criticality.

7.1.5 Printed Wiring Boards

7.1.5.1 Printed Wiring Boards Technical Products

In order to substantiate that the Commercial Provider's alternate documents meet the intent of standards identified in CCT-REQ-1130 for printed circuit board design, fabrication, and assembly, a review of the alternate documents will be conducted.

In addition, the Commercial Provider will provide or make available individual printed circuit board documentation including, but not limited to, vendor conducted test reports, as well as tested and untested coupons that substantiates that the "as-designed" and "as-built" configurations meet the intent of the baseline of requirements established by the applicable standards. In addition to meeting the intent of the requirements outlined in the reference documents, workmanship on printed circuit assemblies will further be verified by successful completion of certification testing, including, but not limited to, the following:

- Electrical component burn-in.
- Thermal cycling (vacuum, if applicable).
- Vibration.

Design of the certification testing will conform to the expected operating environments.

7.1.5.2 Printed Wiring Boards Technical Assessment

Review and analysis of the electrical crewed vehicle battery system design and verification process will determine if a Commercial Provider's standards meet the intent of the following:

- IPC J-STD-001E, *Requirements for Soldered Electrical and Electronic Assemblies Electrical Clearance*.
- IPC J-STD-001ES, *Space Applications Electronic Hardware Addendum to J-STD-001, Requirements for Soldered Electrical and Electronic Assemblies*.
- IPC 2152, *Standard for Determining Current Carrying Capacity in Printed Circuit Board Design*.
- IPC 2220 Series, *Family of Printed Board Design Documents*.
- IPC 6010 Series, *Family of Printed Board Performance Documents*.
- IPC-CM-770E, *Component Mounting Guidelines for Printed Boards*.
- NASA-STD-8739.1, *Workmanship Standard for Polymeric Application on Electronic Assemblies*.
- GEIA-STD-0005-1, *Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-Free Solder*.

Assessment of the Commercial Provider's alternate design/fabrication/assembly standards will place emphasis on the following areas:

- Material selection criteria.
- Plating/final finishes.
- Electrical clearance.
- Conductor width/thickness.
- Vibration mitigation.
- Tin whisker mitigation.
- Thermal management.
- Component placement.
- Holes and interconnects.
- Coupon definition.
- Testing.

7.1.6 Electromagnetic Environment Compatibility

7.1.6.1 Electromagnetic Environment Compatibility Technical Products

Attention to Electromagnetic Environmental Effects and EMC is essential to the operational success of any vehicle design that incorporates electronic, electrical, and electromechanical subsystems operating in dynamically changing electromagnetic environments composed of both man-made and naturally occurring threats, such as the direct and indirect effects of a lightning strike.

The referenced EMC standards documents should be implemented within the design of the commercial vehicle. EMC analysis, design, and test documentation products will be provided as follows, as a basis for successful design validation:

- EMC Control Plan.
- EMC hazard assessment report.
 - Electromagnetic radiation hazards to personnel, ordnance, and volatile materials
 - Hazardous effects of precipitation static (p-static) and direct/indirect lightning activity
 - Electrostatic charge generating mechanisms, to avoid fuel ignition and ordnance hazards, to protect personnel from electrical shock, and to prevent performance degradation or damage to electronics
 - Potential personnel hazards due to high radio frequency (RF) transmitter output powers and antenna characteristics
 - Potential fire hazards due to arcing or sparking from vented or vaporized material
- EMC Analysis and Certification Plan.
- Group A and B test data.*
- List of material used in fabrication.*
- Schematic and assembly drawings.*
- EEE de-rating analysis.*
- Certification standards for test equipment.*

**For MIL-STD-981*

7.1.6.2 Electromagnetic Environment Compatibility Technical Assessment

Review and analysis of the electromagnetic environment compatibility design and verification process will determine if a Commercial Provider's standards meet the intent of the following:

- MIL-STD-461, *Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*.
- MIL-STD-464, *Electromagnetic Environmental Effects Requirements for Systems*.
- MIL-STD-981, *Design, Manufacturing, and Quality Standards for Custom Electromagnetic Devices for Space Applications*.

An assessment of EMC verification products will place emphasis on the quality and completeness of the products in the following review areas:

- EMC requirements traceability report.
- EMC Certification Test Plan.
- EMC certification data.**

***Includes MIL-STD-981 data, which will be reviewed to verify that the device meets the operational and environmental requirements, as well as the compatibility of the materials used.*

7.1.7 Lightning Protection

7.1.7.1 Lightning Protection Technical Products

Lightning is a serious and pervasive threat to hardware on the ground and in flight. Lightning launch commit criteria cannot guarantee 100% that the vehicle will not encounter natural or triggered lightning. Landing flight rules are less restrictive, and may relax weather constraints significantly under emergency conditions, potentially resulting in descent through heavy weather or atmospheric regions conducive to natural or triggered lightning events. For these reasons, the integrated vehicle, equipment, subsystems, and systems must be designed such that they are protected from the indirect effects of nearby lightning. In addition, the integrated vehicle, equipment, subsystems, and systems must be designed such that the crew will survive a direct attachment event. The vehicle should be designed such that structural integrity is protected, thereby avoiding vehicle breakup, and critical systems that could result in catastrophic loss of crew or vehicle remain operational after the event. Crew intervention is acceptable to reset any emergency equipment, subsystems, or systems that are upset by a direct attachment event, although it is desirable that such equipment, subsystems, or systems be automatically reset, if reset is necessary. It is not necessary that the integrated vehicle, equipment, subsystems, and systems be designed such that they will operate without damage or upset through a direct attachment event.

The adequacy of lighting protection designed into the vehicle should be established by the Commercial Provider with the provision of the following products during the vehicle design and development in accordance with the referenced documents:

- Lightning zoning report (report of those vehicle surfaces or structures likely to experience lightning channel attachment and/or current flow between attachment points).
- Lightning current paths analysis.
- Lightning hazards assessment report (report on evaluation of vehicle structures or components whose failure or malfunction due to lightning could contribute to hazardous conditions or events).
- Lightning Protection Plan.
- Lightning Protection Verification Plan.
- Lightning protection verification results/data.

- Lightning actual transient level analysis and equipment transient design level specification report.
- Re-Test Plan to assess the wellness of the vehicle in the event of a lightning strike within the area of the CTS.

7.1.7.2 Lightning Protection Technical Assessment

Review and analysis of the lightning protection design and verification process will determine if a Commercial Provider's standards meet the intent of the following:

- FAA AC 20-136B, *Aircraft Electrical and Electronic System Lightning Protection*.
- SAE ARP 5412A, *Aircraft Lightning Environment and Related Test Waveforms*.
- SAE ARP 5414A, *Aircraft Lightning Zoning*.
- SAE ARP 5577, *Aircraft Lightning Direct Effects Certification*.

An assessment of lightning protection verification products will emphasize the quality and completeness of the products in following review areas:

- Vehicle zoning appropriate to natural environment interaction.
- Detailed assessment of direct and indirect lightning effects to critical/emergency systems.
- Detailed assessment of indirect lightning effects to mission critical systems.
- Application of zoning information to determination of levels of protection from direct lightning effects for spacecraft structure and protection of critical/emergency systems to assure crew survivability in the event of a direct attachment to the spacecraft.
- Application of zoning information to determine appropriate levels of protection from indirect lightning effects for pin and cable induced voltages and currents in mission critical systems.
- Requirements traceability to verification tests.
- Application of adequate design margins.

7.1.8 Electrostatic Controls

7.1.8.1 Electrostatic Controls Technical Products

The control of electrostatic charging and dissipation effects in crewed CTS elements and integrated assemblies should be documented through development and provision of the following products to describe the vehicle design, as well as the establishment and maintenance of workmanship and manufacturing measures and practices:

- ESD Control Plan.
- Triboelectrification controls design assessment.
- Design analysis for ESD protection.
- Survey reporting on compliance with ESD Control Plan provisions.

7.1.8.2 Electrostatic Controls Technical Assessment

Review and analysis of the ESD control process will determine if a Commercial Provider's standards meet the intent of ANSI/ESD S20.20, *Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices)*. The ESD sensitivity of electrical and electronic subassemblies, assemblies, and equipment are expected to be verified by test or analysis at the subassembly, assembly, and isolated equipment levels. ESD sensitivity of equipment in a normal flight configuration is expected to be verified by test. The normal flight configuration of equipment may be simulated in a laboratory environment. Either body/finger or hand/metal human body model (HBM) test methods may be utilized at the subassembly or assembly levels. The hand/metal HBM test method is

expected to be utilized at the equipment level. Analysis is expected to use standard HBM waveforms and test circuits. Verification can be considered successful when the subassembly, assembly, or equipment, isolated and in its normal flight configuration, has demonstrated it is immune to the applicable ESD stimulus.

An evaluation of the Commercial Provider's electrostatic controls will focus on the Commercial Provider's technical standards and technical processes that control and safely dissipate the build-up of electrostatic charges caused by p-static effects, fluid flow, air flow, exhaust gases flow, personnel charging, charging of launch vehicles (including prelaunch conditions) and space vehicles (post deployment), and other charge generating mechanisms, to 1) avoid fuel ignition and pyrotechnic hazards, 2) protect personnel from shock hazards, and 3) prevent performance degradation or damage to electronics.

An assessment of electrostatic controls verification products will emphasize the quality and completeness of the submitted ESD Control Plan and supporting documentation in the following review areas:

- Electrostatic charging and dissipation design requirements traceability.
- Adequacy of controls to satisfy ESD design parameters.
- Component parts inspection and handling.
- Equipment and sub-assemblies marking and labeling processes.
- Manufacturing personnel protective measures and practices.
- Maintenance of adequate controls over product manufacturing life-cycle.
- ESD "design to" goals.

Review of the ESD design thresholds will determine if a Commercial Provider's standards meet the intent of IEC 61000-4-2, *Electromagnetic Compatibility (EMC) Testing and Measurement Techniques - Electrostatic Discharge Immunity Test*. A successful ESD control regime will include industry standard "design to" withstand goals for CTS electrical and electronic equipment, including subassemblies and assemblies to provide protection from damage or fault due to ESD. The minimum industry standard is an HBM discharge at a peak discharge level of 2,000 volts for subassemblies and assemblies and 4,000 volts for equipment. These standards apply specifically to direct contact during non-operating conditions to input, output, and interface connections to subassemblies and assemblies and to direct contact to the case or housing of isolated equipment during non-operating conditions. Any hardware in its normal flight configuration, operating or non-operating, should be immune to upset or damage resulting from exposure to a maximum industry standard HBM discharge of 8,000 volts direct contact or 15,000 volts air-discharge contact to operator accessible points and exposed surface areas of the equipment. These standards do not apply to electrically-initiated explosive devices.

7.1.9 Electrical Bonding

7.1.9.1 Electrical Bonding Technical Products

The adequacy of electrical bonding features implemented for all mechanical interfaces in the integrated space vehicle should be documented by the following products during the vehicle design and manufacturing to meet the intent of NASA-STD-4003, *Electrical Bonding for NASA Launch Vehicles, Spacecraft, Payloads, and Flight Equipment*:

- Electrical Bonding Plan.
- Electrical bonding verification data.

7.1.9.2 Electrical Bonding Technical Assessment

Review and analysis of the electrical bonding design and verification process will substantiate that a Commercial Provider's standards meet the intent of NASA-STD-4003.

An assessment of electrical bonding verification products will place emphasis on the quality and completeness of the products in the following review areas:

- Identification of electrical bond paths.
- Proper allocation of electrical bonding classes to mechanical interfaces.
- Analysis of applied electrical bonding processes.
- Test measurements of installed electrical bonds.

7.1.10 Low Earth Orbit Spacecraft Charging

7.1.10.1 Low Earth Orbit Spacecraft Charging Technical Products

In order to substantiate that the Commercial Provider meets the intent of NASA-STD-4005, *Low Earth Orbit Spacecraft Charging Design Standard*, and to certify their design for high-voltage space power systems (>55 volts) that operate in low Earth orbit (LEO), emphasis, as a minimum, will be placed on designs that do not produce hazards or mission success issues with respect to EMI/EMC effects on photovoltaic efficiency or avionics, power, thermal control and pyrotechnic system reliability due to:

- Surface arcing.
- Parasitic current loss comparable to power system margin.
- Parasitic plasma currents.

Commercial Provider vehicle designs must limit current collected from the space plasma environment when docked to the ISS to levels within the current constraints specified in SSP 50808.

7.1.10.2 Low Earth Orbit Spacecraft Charging Technical Assessment

Review and analysis of the spacecraft's power system's design for prevention and mitigation/control of spacecraft exterior charging and verification process will determine if a Commercial Provider's standards meet the intent of NASA-STD-4005.

Verification of LEO space systems' performance should not be attempted solely by analysis without advanced concurrence from the responsible NASA Program Office. Assessment of the Commercial Provider's alternate spacecraft exterior charging in LEO control standards will place emphasis on simulated LEO plasma environmental test data under worst case simulated operational conditions. There may be some cases where only an analysis will suffice. Final decision on whether a simulated environmental test is required will require Program Office concurrence.

7.1.11 Communication and Spectrum Management

7.1.11.1 Communications

In order to substantiate that the Commercial Provider meets the requirements of CCT-REQ-1130 that insure acceptable RF communications performance and compatibility with other spectrum users, emphasis will be placed on the following:

- Compliance to the Space Network Users Guide requirements (current revision). Verify if tracking and data relay system (TDRS) service is planned by analysis and space network category 1 and category 2 compatibility tests.

- Compliance with spectrum standards as stated in Section 7.1.11.2.
- For space-to-ground transmission, transmitter can only be on when a capable ground station is in view of the spacecraft and must be able to control power on/off.
- Maximum BW per channel in S-band limited to 5MHz downlink and 6.14 MHz for space-to-space links.
- RF performance standards are specified for the ideal condition; however, expected aggregate interference degradation based on an expected RF environment, structure blockage, vehicle orientation, antenna pointing direction, etc., should be factored into the final verification of 90% communications during ascent and 65% communications during reentry.
- ISS frequency compatibility – spacecraft RF must meet interface requirements of SSP 50808, cannot impede/constrain operation of the ISS, and cannot require the ISS to operate in non-standard attitudes to accommodate communications.
- Inclusion of power control capability to reduce transmit output power for safety considerations, especially when in close proximity operation of the ISS or radiating when docked.
- A minimum BER of 10E-08 measured at the output of a decoder with a 3dB margin should be maintained. This BER is not to be confused with the BER of the RF channel, which is typically much higher (10E-03, 10E-04).

7.1.11.2 Spectrum Utilization Standards

The following criteria is necessary to assure compatibility with NASA's deep space operation and minimize interference to TDRS space network multiple access users. Non-compliance will result in operational constraints and additional limitations regarding operation of the spacecraft links in adjacent bands.

Maximum Interference Power Spectral Flux Density	
Frequency	Maximum interference power spectral flux density (dB(W/m ² /Hz))
2290-2300 (MHz)	-257
8400-8450 (MHz)	-255.1
31.8-32.3 (GHz)	-249.3

MAXIMUM RADIATED POWER FOR SYSTEMS EMPLOYING SN RETURN LINKS AT A FREQUENCY OF 2287.5 MHz	
Case	Maximum Radiated EIRP (dBW)
CTS Systems Transmitting Operational Point-to-Point Links to TDRSS	25.1 ¹
Note: ¹ The maximum EIRP value is based on the use of right hand circular polarization (RHCP). A reduction in maximum EIRP value would result if left hand circular polarization (LHCP) is employed	

7.1.12 Avionics and Electrical Systems References

Document Number	Revision	Title
AIAA S-111-2005		Qualification and Quality Requirements for Space Solar Cells
AIAA S-112-2005		Qualification and Quality Requirements for Space Solar Panels

Document Number	Revision	Title
ANSI C63.16		<i>American National Standard Guide for Electrostatic Discharge Test Methodologies and Criteria for Electronic Equipment</i>
IEEE STD C62.38		<i>IEEE Guide on ESD: ESD Withstand Capability Evaluation Methods (for Electronic Equipment Subassemblies)</i>
JPR 8080.5		<i>JSC Design and Procedural Standards</i>
SAE ARP 5416		<i>Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning</i>
RTCA DO-160E	Rev. E	<i>Environmental Conditions and Test Procedures for Airborne Equipment (Sections 22 and 23)</i>

7.2 EEE (Electrical, Electronic, and Electromechanical) Parts Management

The EEE Parts Management Plan establishes the minimum technical requirements for electronic parts used in the design, development, and fabrication of electronic hardware for the crew and launch vehicle. The plan should manage and control the selection, acquisition, traceability, testing, handling, packaging, storage, and application of the EEE parts in the CTS.

The CTS subsystems should emphasize parts selection that fit the application, the environment, reliability and assurability for a human-rated program. The best practices for the development and implementation of an Aerospace EEE Parts Control Plan can be found in several Military and/or NASA standards listed below:

- SMC Standard SMC-S-010, *Space and Missile Systems Center Standard, Parts, Materials, and Processes Technical Requirements for Space and Launch Vehicles*.
- MSFC-STD-3012, *Electrical, Electronic, and Electromechanical (EEE) Parts Management and Implementation Plan for MSFC Space Flight Hardware* or an equivalent document.

7.2.1 EEE Parts Management Technical Products

A comprehensive EEE Parts Verification and Implementation Plan as described in SMC Standard SMC-S-010 or MSFC-STD-3012 or an equivalent document should be established. An analysis/review of the following design documentation will determine the adequacy of the implementation of this plan:

- EEE Parts Selection Plan and screening process (note: contained in Paragraph 7.1.1).
- As-designed and as-built EEE parts list (note: contained in Paragraph 7.1.1) including rationale behind the use of less than the highest reliability parts which addresses the application, including performance, environment, criticality, and mission lifetime.
- De-rating and application analysis (an example of NASA typical wire/cable de-rating criteria can be found in of SSP 30312, Appendix B).

7.2.2 EEE Parts Management Technical Assessment

In order to substantiate that the alternate documents meet the intent of standards identified in CCT-REQ-1130 for EEE parts, a review of the EEE Parts Management Plan and support documentation will be conducted. The plan should ensure the reliability of the EEE parts used through elimination of infant mortality, die attach, wire bonding, and the overall part assembly process anomalies. Emphasis will be placed in the following areas for compliance:

- EEE parts requirements.

- EEE parts selection
 - Minimum grade of EEE part to be used based on criticality, redundancy, and failure tolerance of the system
 - Typically Class S for critical, non-redundant, non-failure tolerant systems and Class B for redundant, failure tolerant systems.
- Parts qualification and 100% screening when the minimum grade cannot be obtained
 - Destructive physical analysis (per lot)
 - Particle impact noise detection (per part)
 - Thermal cycling (per part)
 - Burn-in (per part)
 - X-ray analysis (per part)
 - Ionizing radiation hardness assurance for each lot of parts
- Pure Tin Mitigation Plan should meet the intent of GEIA-STD-0005-2
- Counterfeit Parts Control Plans (reference SAE/AS5553), including control of parts obsolescence
 - Use of trusted sources
 - Commercial Off the Shelf (COTS)/Military Off the Shelf (MOTS) analysis/screening
- EEE Parts procurement processes.
 - Vendor controls
- The process for traceability and reporting of non-conformances should be defined in the Provider's Non-conformance Plan.
- EEE parts controlling specifications.
- Parts assurance actions, including audits.
- ESD Implementation Plan should meet the intent of ANSI/ESD S20.20.
- Ionizing Radiation Control Plan that defines the test regime necessary to meet the environment. For on-orbit, this environment is specified in SSP 30512, *Space Station Ionizing Radiation Design Environment*.

7.2.3 EEE Parts Management References

Document Number	Revision	Title
AS5553		<i>Counterfeit Electronic Parts; Avoidance, Detection, Mitigation, and Disposition</i>

7.3 Mechanical Systems

7.3.1 Mechanisms Subsystem

Mechanisms are components and systems in which mechanical parts move relative to one another in order to provide some desired function on the spacecraft. Correct operation of the mechanism subsystem is required to ensure crew safety and mission success.

The mechanism subsystem should employ designs which can be readily submitted to engineering analyses, while conforming to standard aerospace industry practices. The designs should utilize materials having mechanical properties that are well characterized for the intended service environments and design conditions. Likewise, all sub-components used in the design of mechanisms should have well understood and predictable performance in the intended service environments and design limits. These component items may include, but are not limited to, switches, bearings, motors, dampers,

clutches, torque limiters, lubricants, springs, and valves (including use in fluids and propulsion systems). For reusable and multi-mission hardware, these criteria are applicable throughout the service life of the mechanism.

The best practices for this design and verification process and its associated documentation can be found in the relevant NASA standard, described below:

- NASA-STD-5017, *Design and Development Requirements for Mechanisms*. Section 4.7, *Fastener Retention* and Section 4.8.9, *Preload Bolt Criteria* may be excluded, as the best practices for structural fasteners are contained within other NASA documentation. NASA-STD-5017 provides an excellent set of guidelines for the design and development of any aerospace mechanism. Much of the guidance specified within this standard has been derived from lessons learned throughout the NASA agency and across multiple flight programs.

7.3.1.1 Mechanisms Subsystems Technical Products

The Commercial Provider should provide design documentation to substantiate that all vehicle mechanisms have been adequately designed and verified, and demonstrate that they meet the intent of NASA-STD-5017. An analysis/review of the following design documentation will determine the adequacy of mechanism design standards:

- Design drawings and specifications that fully describe the mechanism subsystem and components, as well as their proper integration into the flight vehicle.
- Detailed engineering analysis of each mechanism subsystem, including a complete summary of mechanism torque/force margins where applicable, and also the margins of safety for each mechanism sub-component within the allowable mechanism rigging tolerances.
- A full description of any computational models and methods used in the analysis, a description of the assumptions used to facilitate the modeling, as well as the testing which supports the assumptions within these models.
- Test plans, results, and reports, to include but not limited to, qualification testing, acceptance testing, design life and cycle testing, and environmental testing.
- An analysis of the criticality of each mechanism on the spacecraft with regards to its implication for crew safety.

7.3.1.2 Mechanisms Subsystems Technical Assessment

A review of the mechanism design and verification documents will place emphasis on the following areas:

- Mechanism design, performance, integrity, and operability for all mission phases, including pre-mission integrated testing, and post-mission recovery and vehicle safing.
- Validation that Commercial Provider verification tests adhere to “test like you fly” philosophy.
- Review of component, subsystem, and system requirements traceability from the vendor to the primary Commercial Provider.
- Review of acceptance and qualification data (test plans, procedures, and reports) to verify CTS, including refurbished or re-flown products, meets performance specifications, demonstrates acceptable quality and workmanship, and is ready to be committed to flight. Review and assessment of subsystems and unit qualification and acceptance data will determine if a Commercial Provider’s standards meet the intent of SMC-S-016, *Test Requirements for Launch, Upper-Stage, and Space Vehicles*.

7.3.2 Pyrotechnics Subsystem

7.3.2.1 Pyrotechnics Subsystem Technical Products

The “one time, every time” single use nature of pyrotechnic devices and the criticality of their associated functions require that a confidence be instilled through thorough documentation, review, and test of the component lot build parts and processes.

Typically, documentation that substantiates that the individual pyrotechnic components and the pyrotechnic systems have been adequately designed, manufactured, and tested to demonstrate compliance with the intent of this requirement using a documented, accepted standard (e.g., JSC 62809D) will be generated. Documentation provided should include:

- Concept of operation and design detail of each pyrotechnic system, including layouts, identification of components, interfaces/interconnect detail, and identification of fault tolerance within each system.
- Worst-case predicted natural and induced environments for each device/system.
- Design specification and source control or vendor control drawing for each device.
- Baseline review and production review documentation for each device (i.e., Phase I and Phase II review data per JSC 62809D).
- Development test reports with accompanying technical data.
- Margin test reports with accompanying technical data.
- Qualification test plans and reports with accompanying technical data.
- Analyses supporting qualification of each device and system.
- Lot acceptance data information and data package (i.e., Phase III review data per JSC 62809D).
- Age life test plans and reports with accompanying technical data.

7.3.2.2 Pyrotechnics Subsystem Technical Assessment

Review and analysis of the pyrotechnic subsystem design and verification process will determine if a Commercial Provider’s pyrotechnic standards address the requirements in and meet the intent of JSC 62809D, *Human-Rated Spacecraft Pyrotechnic Specification*.

A review of the submitted documentation will place emphasis on the following areas:

- Mission criticality.
- Applicability of the component to its intended system function.
- Component and piece parts traceability up to and including powders.
- Testing to demonstrate margin.
- Detailed analysis and testing to verify the component’s ability to properly function after exposure to natural and induced environments.
- Component phase reviews of critical systems as defined within JSC 62809.
- Evaluation of the failure tolerance of each pyrotechnic subsystem design to verify single fault tolerance for fails to operate failure modes. If not completely fault tolerant, an evaluation of data that demonstrates that design sensitivities are understood and failure modes mitigated.
- Review of lot acceptance data, which will occur on a recurring basis for every production lot, to verify:
 - Each lot is of the same design and construction, fabricated in one unchanging and essentially continuous manufacturing process, with traceability maintained on each device and piece part/material.

- Only one lot of each explosive or pyrotechnic material is used in a lot of explosively loaded components or devices.
- Successful performance of non-destructive lot acceptance tests on 100% of each production lot of devices.
- Successful performance of destructive lot acceptance testing conducted after completion of non-destructive tests on a randomly selected sample of the production. The destructive lot acceptance testing includes subsection of the components to specified thermal and dynamic environments prior to performance test.
- Review of qualification reports and data for each pyrotechnic device and system. The review will verify that testing has utilized test hardware of the same configuration and manufactured under the same production process as the flight hardware, and that hardware properly functions after exposure to the worst case natural and induced environments anticipated during its operational life.
- Evaluation of auto ignition temperature testing and analysis for the explosive materials selected to verify that they will not auto ignite when subjected to 50 °F above the maximum predicted thermal exposure for which the device is designed.
- Evaluation of pyrotechnic and explosive materials seal designs to verify that loaded components are sealed to a leak rate not greater than 1×10^{-6} cc/second of helium when measured at one atmosphere differential pressure.
- Evaluation of threaded parts to ensure appropriate engagement and captive features with an expectation that all parts are positively locked.
- Evaluation of the design of pressure actuated devices to verify that components exposed to operating pressure are capable of withstanding an internal static proof pressure of 1.2 times the maximum operating pressure without permanent deformation or leakage, and an internal pressure of 1.5 times the maximum operating pressure without structural failure (burst).
- Evaluation of the design of pressure actuated devices to ensure they are capable of withstanding internal pressures generated in operation with the movable part restrained in its initial position and without rupture or the release of shrapnel, debris, or hot gases that could compromise crew safety or mission success.
- Evaluation of the compatibility of materials used in devices to verify that all materials are compatible with each other to the extent that no reaction occurs that might adversely affect the component or system performance or safety.
- Evaluation of each pyrotechnic system design to verify that the designs preclude incorrect installation and assembly.
- Evaluation of margin test results on pyrotechnic component interfaces, component performance and, as applicable, subsystem performance.
- Evaluation of Commercial Provider's proposed age life evaluation methodology to verify that testing will be conducted at specific intervals to demonstrate that performance characteristics continue to meet lot acceptance criteria without significant degradation.
- Evaluation of the Commercial Provider's pyrotechnic device configuration control, which should be unique for its pyrotechnic devices and should be established and maintained for the design, manufacturing processes, materials, inspection, acceptance, and qualification of all pyrotechnic devices.

7.3.3 Purge, Vent, Drain Subsystems

7.3.3.1 Purge, Vent, Drain Subsystem Technical Products

In support of design validation, the following products will be used to substantiate that the purge, vent, drain (PVD) systems have been adequately designed, assembled, tested, serviced, and verified:

- Purge and vent products.
 - Vehicle purge
 - Thermal/humidity control analysis
 - Hazardous Gas Detection Plan
 - Cavity inerting analysis
 - Vehicle cavity and PVD system venting analysis

7.3.3.2 Purge, Vent, Drain Subsystem Technical Assessment

Evaluation of the PVDs systems documentation products will focus on establishing confidence in the products, hardware design, and processes. Confidence will be established by assessing the provided documentation products against Government and industry standards, lessons learned, and best practices where they exist and are relevant to the PVD systems under assessment.

Assessments of PVD systems will place emphasis on the following:

- Evaluation of the vehicle conditioning/purge ground system and concept of operations to verify the expected operation and requirements are met in accordance with the vehicle thermal/humidity design analysis, the Hazardous Gas Detection Plan, the cavity inerting analysis, and the vehicle cavity and PVD system venting analysis.
- Assurance that the PVD system is designed to optimize a safe environment for the crew and ground personnel.

7.3.4 Purge, Vent, Drain Subsystem References

Document Number	Revision	Title
SP-8060		<i>Compartment Venting, NASA Space Vehicle Design Criteria</i>
NASA-STD-5001		<i>Structural Design and Test Factors of Safety for Spacecraft Hardware</i>

7.4 Structures

Structures are components and assemblies designed to sustain loads or pressures, provide stiffness and stability, or provide support or containment. Internal components are not considered primary structures if their failure would not result in a critical or catastrophic hazard.

Flight hardware structure must maintain structural integrity during the service life of the spacecraft and launch vehicle, including damage tolerance capability and resistance to effects of aging on the hardware, as applicable. The design loads are determined by the integrated system loads analysis or analysis of subsystem flight or ground events, and are defined in the Loads Control Plan.

The launch vehicle and spacecraft structural subsystems should employ designs that are amenable to engineering analyses by current state-of-the-art methods and conforming to standard aerospace industry practices. More specifically, the designs are assumed to use materials having mechanical properties that are well characterized for the intended service environments and all design conditions. For reusable and

multi-mission hardware, these criteria are applicable throughout the service life and all of the missions. Repaired or refurbished structures must meet the design and verification standards for new hardware. The best practices for this design and verification process and its associated documentation can be found in the relevant NASA standards, described below:

- Use JSC 65828, *Structural Design Requirements and Factors of Safety for Space Flight Hardware* for primary structure, other than windows.
- To mitigate the risk of catastrophic structural failure due to the presence and growth of flaws or damage throughout the service life, use NASA-STD-5019, *Fracture Control Requirements for Space Flight Hardware* for fracture control.
- For design and verification of all liquid propellant engines, use NASA-STD-5012. The intent of NASA-STD-5012 was for liquid propellant rocket engines with thrust greater than 6000 lbs based on lessons learned from engines in higher thrust classes; therefore, the requirement specified in NASA-STD-5012 will require tailoring for liquid propulsion engine systems with less than 6000 lbs of thrust. Simplification may include relaxing requirements, such as the required number of structural qualification engines and/or tests. Structural factors of safety for these smaller propulsion systems are provided in JSC 65828, along with some recommended tailoring of NASA-STD-5012.
- For design and verification of glass or ceramic structural components, including windows, use NASA-STD-5018, *Strength Design and Verification Criteria for Glass, Ceramics, and Windows in Human Space Flight Applications*.
- Design and verification best practices for structural fasteners are addressed in NASA-STD-5020, *Requirements for Threaded Fastening Systems in Spaceflight Hardware*.

A Commercial Provider may choose existing standards or maintain their own technical standards for structural design and verification, and may propose this substitution subject to NASA CCP approval. Technical standards are not intended to address every contingency; therefore, design factors may be tailored to reflect the rigor applied to understanding typical uncertainties in the design or performance of the structural subsystem, including predicted loads and environments, predicted structural response, load path simplicity, material properties, manufacturing or maintenance variability, and damage tolerance capabilities.

7.4.1 Structures Subsystem Technical Products

A comprehensive SVP (as described in JSC 65828) documenting the full structural analysis, test, and assessment program provides the basis for successful design validation.

NASA expects to review the SVP at all design and engineering milestones. The initial delivery of the SVP should occur early in the design phase, before more than 40% of the drawings are released. The fidelity at this first review should be detailed enough to define the structural verification approach, including planned development testing.

The SVP must be maintained and updated, because the hardware design and the design data will evolve as the loads, mass properties, temperatures, and other environments are verified. The SVP should be updated prior to the final design review to support these evolutions and to update the structural verification approach, as needed.

In support of design validation, the Commercial Provider should prepare documentation that substantiates that the structure has been adequately designed and verified to meet the intent of standards described herein.

The documentation should include:

- An SVP (as described in JSC 65828).
- Glass and Ceramics Verification Plan (as described in NASA-STD-5018) that outlines how structural glass and ceramics will be verified.
- Design drawings that fully describe the subsystem and components and their assembly into the flight vehicle.
- Detailed stress analysis, including a complete summary of the minimum margin of safety for each structural part.
- A full description of the numerical models and methods used in the analysis and the tests that validate those models.
- Test plans, results, and reports, including structural and damage tolerant certifications of composite/bonded structures by building block testing.
- Test plans, results, and reports describing the verification results for glass and ceramics.
- A Fracture Control Plan (FCP) and Fracture Control Summary Report (FCSR) as outlined in Section 8.1 of this document.

7.4.2 Structures Subsystem Technical Assessment

NASA's review of the structural design and verification documents will place emphasis on the following areas:

- Primary structure design functionality and integrity for all mission phases.
- Validation that Commercial Provider verification tests adhere to "test like you fly" philosophy.
- Review of component, subsystem, and system requirements traceability from the vendor to the primary Commercial Provider.

7.4.3 Thermal Protection System

7.4.3.1 Thermal Protection Systems Technical Products

The fundamental purpose of the spacecraft's Thermal Protection System (TPS) is to protect the vehicle from the ascent and reentry environments and maintain structure temperatures within specified limits. The TPS presents catastrophic hazards and will contain elements that cannot be practically designed with any level of failure tolerance.

JSC 65827, *Thermal Protection System Design Standard for Spacecraft* provides the best practices for the design and verification of the TPS, and is the approved standard for addressing the absence of TPS failure tolerance. Thus, documentation must be provided that substantiates that the TPS has been adequately tested and/or analyzed to meet the intent of JSC 65827. It is recognized that Commercial Providers may choose existing standards or maintain their own technical standards for TPS design, analysis, and test under the condition that the detailed intent of JSC 65827 is met.

To the extent specified in JSC 65827, the following documents should also be applied to the TPS:

- For structural design and verification of the TPS, use JSC 65828, *Structural Design Requirements and Factors of Safety for Space Flight Hardware*, or equivalent.

- For fracture control of the TPS, use NASA-STD-5019, *Fracture Control Requirements for Spacecraft*, or equivalent.
- For M&P associated with the TPS, use NASA-STD-6016, *Standard Materials and Processes Requirements for Spacecraft*, or equivalent.

Specific Commercial Provider provided products that should be developed in order to demonstrate flight certification of the TPS include, but are not limited to, the following:

- TPS Certification Plan.
- Requirements and description document.
- Risk Management Plan.
- Subsystem/component specifications.
- Materials Properties Plan and report, including material allowable.
- Qualification test plans and reports.
- Thermal and structural analysis reports, including margin policy and model validation reports.
- Damage tolerance assessment, including Micro Meteoroid Orbital Debris (MMOD).
- Reliability Assurance Plan and analysis reports.
- Quality Assurance Plan, data, and documentation.
- Acceptance data package.

7.4.3.2 Thermal Protection Systems Technical Assessment

TPS certification is primarily implemented through a verification and validation program applied to the TPS design through the development and qualification program, and applied to the TPS hardware through an acceptance program. TPS certification requires not only that the TPS satisfy its allocated functional and interface requirements at all levels, but also that TPS operational environments are understood for all mission phases and the TPS response to those environments is understood and predictable. An evaluation of the submitted TPS certification documentation will place emphasis on the following areas:

- Verification of functionality, design, and integrity for all mission phases.
- Detailed thermal/structural analysis, including a fully substantiated margin policy and analytical model validation evidence.
- Test data:
 - Aerothermal testing at coupon and element (as applicable) levels to demonstrate performance in the predicted environment and potential failure modes.
 - Material property testing and results.
 - Structural and thermal/structural testing at coupon, element, sub-component and component/vehicle levels.
- Component, subsystem, and system requirements traceability and knowledge and verification of environments.

7.4.4 Structures Subsystem References

Reference documents are listed in the documents and standards described above. Not all of the following documents are in every standard discussed in this section of CCT-STD-1140.

Document Number	Revision	Title
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ANSI/AIAA S-080-1998		<i>Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components, September 13, 1999</i>
ANSI/AIAA S-081A-2006		<i>Space Systems - Composite Overwrapped Pressure Vessels (COPVs), July 24, 2006</i>
ASTM C1368		<i>Standard Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by constant Stress-Rate Flexural Testing at Ambient Temperature</i>
ASTM C1421-01b		<i>Standard Test Methods for Determination of Fracture Toughness of Advanced Ceramics at Ambient Temperature</i>
ASTM C1576		<i>Standard Test Method for Determination of Slow Crack Growth Parameters of Advanced Ceramics by Constant Stress Flexural Testing (Stress Rupture) at Ambient Temperature</i>
JSC 28918		<i>EVA Design Requirements and Considerations</i>
JSC 65827	Rev. A	<i>Thermal Protection System Design Standard for Spacecraft</i>
JSC 65828	Rev. B-1	<i>Structural Design Requirements and Factors of Safety for Space Flight Hardware</i>
JSC 65829	Rev. A	<i>Loads and Structural Dynamics Requirements for Space Flight Hardware</i>
JSC 65831		<i>Fracture Control Standard for Spacecraft</i>
MIL-HDBK-60		<i>Threaded Fasteners-Tightening to Proper Tension</i>
NASA-STD-5012	Baseline	<i>Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines</i>
NASA-STD-5001		<i>Structural Design and Test Factors of Safety for Spacecraft Hardware</i>
NASA-STD-5017		<i>Design and Development Requirements for Mechanisms</i>
NASA-STD-5018	Baseline	<i>Strength Design and Verification Criteria for Glass, Ceramics, and Windows in Human Spaceflight Applications</i>
NASA-STD-5019		<i>Fracture Control Requirements for Space Flight Hardware</i>
NASA-STD-5020	Baseline	<i>Requirements for Threaded Fastening Systems in Spaceflight Hardware</i>
NASA-STD-6008		<i>NASA Fastener Procurement, Receiving Inspection, and Storage Practices for Space Flight Hardware</i>
NASA-STD-6016		<i>Standard Materials and Processes Requirements for Spacecraft</i>
NASA-STD-7001		<i>Payload Vibroacoustic Test Criteria</i>
NASA-TM-X-73305		<i>Astronautic Structures Manual</i>
NPR 8705.4		<i>Risk Classification for NASA Payloads</i>
SSP 50808		<i>ISS to Commercial Orbital Transportation Services Interface Requirements Document</i>

7.5 Fluid Systems

The launch vehicle, spacecraft, and crew systems design may include liquid and gaseous fluid systems that utilize, control, or supply fluids. Fluids systems may include, but are not limited to, water, oxygen, cryogenic systems, storables, hydraulic fluids, pressurization fluids (including helium and nitrogen), thermal conditioning, and environmental control fluids. Any and all associated fluid storage, lines, fittings, valves, and other fluid components are considered part of the fluid systems. The design,

assembly, test, and certification of all fluid systems must be adequately documented and must be available for review throughout all stages of the fluids system development life-cycle. Proper design and integration of fluid systems is essential to ensure crew safety and mission success.

Many sections of this document and the CTS requirements document reference technical products that compliment fluids system design. These products not only apply at the integrated vehicle-level, but are also applicable at the subsystem-level. These products are not repeated here, but will be evaluated as critical to fluid systems, and this section must be augmented with those other technical products to be considered complete (e.g., hazard analysis).

7.5.1 Fluids Subsystem Technical Products

In support of design validation, the following products will be used to substantiate that the fluid systems have been adequately designed, assembled, tested, serviced, and verified:

- Systems design analysis for each subsystem, including but not limited to:
 - Design drawings and specifications that fully describe the subsystem and components, as well as their integration into the flight vehicle.
 - Fluid subsystems mission operation plans, including emergency/contingency operations.
 - Summary of verification test, analyses, and controls for fluids whose leakage is hazardous.
 - Engineering analysis of each subsystem showing margins, including but not limited to:
 - Pressure budget analysis and subsystem performance analyses, addressing nominal conditions, tolerance effects, and failure effects.
 - Pressure and thermal control analysis
 - Composite Overwrapped Pressure Vessel (COPV) and pressure vessel design.
 - Flow induced vibration analysis.
 - Flow test plans and reports
 - Fluid line design (combined pressure/thermal/mechanical load analysis).
 - Fatigue analysis, non-hazardous leak before burst (NHLBB), and /or safe life analysis.
 - Transient pressure analysis for design and operational impacts.
 - Consumables management analysis.
 - Mission assumptions
 - Usage plans
 - Allowable leakage.
 - Relief mechanisms.
 - Material analysis and fluid compatibility.
 - Oxygen compatibility assessment
 - Material uses
 - Processes
 - Materials exposed to hazardous fluids will be evaluated or tested for compatibility (as referenced in NASA-STD-6016)
- Acceptance and qualification test plans and methods.
 - Analysis/inspection reports
 - Demonstration test results
 - Test procedures results and pass/fail criteria
- Integrated fluid system testing results, including but not limited to:
 - Integrated software/avionics and fluid system testing.
- Requirements verification report.

- Fabrication Process Control Plan.
- Inspection Plan, including nondestructive evaluation (NDE), and inspector certification program.
- Fluid servicing and ground operating procedures.
- Contamination Control Plan (as referenced in NASA-STD-6016).
- Fluid use and procurement specification.

7.5.2 Fluid Subsystem Technical Assessment

Evaluation of the fluids systems documentation products will focus on establishing confidence in the products, hardware design, and processes. Confidence will be established by assessing the provided documentation products against Government and industry standards, lessons learned, and best practices where they exist and are relevant to the fluid systems under assessment.

Assessments of fluid systems will place emphasis on the following:

- Evaluation of fluid system related design and hazard analysis, reliability analysis, separation of critical redundant systems assessments, plans, and operations to determine that integrated components and systems will operate as designed and will not cause injury to the crew or damage to the system.
- Evaluation of models, simulation data, and reports to assess whether models and simulations used in the design and certification of fluid systems have been properly validated, utilized, and are configuration controlled. Review and analysis of the modeling and analysis methodology will determine if a Commercial Provider's standards meet the intent of JSC 65829, *Loads and Structural Dynamics Requirements for Space Flight Hardware*.
- Evaluation of Inspection Plan and inspection certification program to ensure appropriate inspection milestones are planned.
- Review of fluid component design products to verify that the design requirements are met. Review and analysis of the component design will determine if a Commercial Provider's standards meet the intent of NASA-STD-5017, *Design and Development Requirements for Mechanisms*.
- Evaluation of pressure vessel and COPV analysis to verify that design requirements are met. Review and analysis of the design and verification process will determine if a Commercial Provider's standards meet the intent of JSC 65828, *Structural Design Requirements and Factors of Safety for Space Flight Hardware*; AIAA S-080, *Space Systems-Metallic Pressure Vessels, Pressurized Structures, and Pressure Components*; and AIAA S-081A, *Space Systems Composite Overwrapped Pressure Vessels*.
- Evaluation of NHLBB pressure component design to verify that design requirements are met. Review and analysis of the component design will determine if a Commercial Provider's standards meet the intent of NASA-STD-5019, *Fracture Control Requirements for Space Flight Hardware*.
- Review of acceptance and qualification data (test plans, procedures, and reports) to verify that the CTS (including refurbished or re-flown products) meets performance specifications, demonstrates acceptable quality and workmanship, and is ready to be committed to flight. Review and assessment of subsystems and unit qualification and acceptance data will determine if a Commercial Provider's standards meet the intent of SMC-S-016, *Test Requirements for Launch, Upper-Stage, and Space Vehicles*.
- Review of fluid servicing and ground operating procedures to verify that fluid system integrity is maintained. Review and analysis of the system ground and flight design will determine if a Commercial Provider's standards meet the intent of NASA-STD-6016.

- Evaluation of systems consumables analysis and loading procedures to ensure adequate margin in accordance with Nominal Mission Plan analysis documents, including contingency and emergency scenarios as developed by the CCP.

7.5.3 Flow-Induced Vibration (FIV) for Flexhoses and Bellows

The occurrence of flow-induced vibrations in convoluted metal bellows and flexhoses can result in a catastrophic structural fatigue failure. Grazing flow across the convolutes may result in vortex formation and shedding from the tips of the convolutions. When the frequency of this vortex shedding coincides with one of the natural longitudinal resonant frequencies of the bellows or flexhose structure, then a strong bellows flow induced vibration (“lock-in”) can exist. Therefore, all CTS flexhoses and bellows must be analyzed for the existence of FIV over their operating flow range $\pm 10\%$ in accordance with MSFC-DWG-20M02540, *Assessment of Flexible Lines for Flow-Induced Vibration* or an approved alternate standard with the following exceptions:

- Metal bellows and flexhoses with full flow liners that preclude FIV
- Metal bellows and flexhoses with steady-state flow less than one second duration
- Metal bellows and flexhoses which experience an operating flow environment that is different (atypical flow) than the FIV phenomena described in MSFC-DWG-20M02540 and also beyond the capability of MSFC-DWG-20M02540 to predict. However, an alternative analysis technique should be developed as described later on in this section.

The following, along with Figure 7.5.3-1, outlines the process for design acceptability to minimize the likelihood of a catastrophic failure of bellows and flexhoses.

- The primary objective is to eliminate FIV through design. This is accomplished when the analysis per MSFC-DWG-20M02540 shows that FIV does not exist in the operating flow range $\pm 10\%$.
- When the MSFC-DWG-20M02540 analysis predicts FIV and redesign is not achievable the following must occur:
 - a) Incorporation of additional design robustness such as integration of flow liners.
 - b) Performance of a resonant flow test to show an acceptable life in accordance with MSFC-SPEC-626, *Test Control Document for Assessment of Flexible Lines for Flow Induced Vibration* or an approved alternate standard.
 - i) The first part of the resonant flow test performs a resonance search to determine if flow coupling occurs and if so, at what flowrate and frequency. The design is acceptable if coupling is shown not to occur. This outcome is due to conservatism associated with the MSFC-DWG-20M02540 analysis for predicting FIV.
 - ii) The second part of the resonant flow test is implemented when coupling is detected during the resonant search test above, and consists of dwelling at the most severe resonant condition until the number of cycles equivalent to four times the operational life have been accumulated at the resonance condition. The design is acceptable if the

bellows or flexhose survives this flow test (i.e., shows no indication of fluid leakage or detrimental damage).

The following applies **only** to ground systems and equipment bellows and flexhoses, whose failure due to FIV does not result in a situation that jeopardizes the safety of personnel or cause damage/degradation of flight hardware during test operation or ground processing. When FIV is predicted in the MSFC-DWG-20M02540 analysis for these ground systems and equipment bellows and flexhoses, and redesign is not achievable, the following must occur to achieve design acceptability:

- Performance of a fatigue life analysis in accordance with MSFC-DWG-20M02540. The design is acceptable when the analysis shows a theoretical infinite life and when the maximum operating flow velocity through the flexible line is limited in accordance with MSFC-DWG-20M02540.
- Performance of a resonant flow test in accordance with MSFC-SPEC-626 when a fatigue life analysis predicts a finite life. This resonant flow test consists of dwelling at the most severe resonant condition until the number of cycles equivalent to four times the operational life have been accumulated at the resonance condition. The design is acceptable if the bellows or flexhose survives this flow test (i.e., shows no indication of fluid leakage or detrimental damage).

An evaluation should be made in the design process for each bellows and flexhose to determine if the MSFC-DWG-20M02540 is applicable or not. For those metal bellows and flexhoses which experience an operating flow excitation environment that is different than the grazing flow environment described by MSFC-DWG-20M02540, or beyond the capability of MSFC-DWG-20M02540 to predict, then an alternative analysis technique must be used to determine if any FIV occurs over the operating flow range $\pm 10\%$. This different flow excitation environment is called “atypical flow”. The alternative analysis technique and assumptions used must be shown to be conservative and valid through an appropriate test program.

Examples that may cause atypical flow are as follows:

1. Strong back flow swirl from a turbopump located just downstream of a bellows that alters the flow across the convolutes.
2. Partial flowliners where several of the bellows convolutes are not protected by the partial flowliner.
3. A bellows where the inside diameter of the convolute roots is greater than the inside diameter of the smooth wall just upstream of the convolutes (i.e the design has convolutes recessed from the main flow field).

Evaluation of the fluids systems documentation products will focus on establishing confidence in the products, hardware design, and processes. Confidence will be established by assessing the provided documentation products against Government and industry standards, lessons learned, and best practices where they exist and are relevant to the fluid systems under assessment.

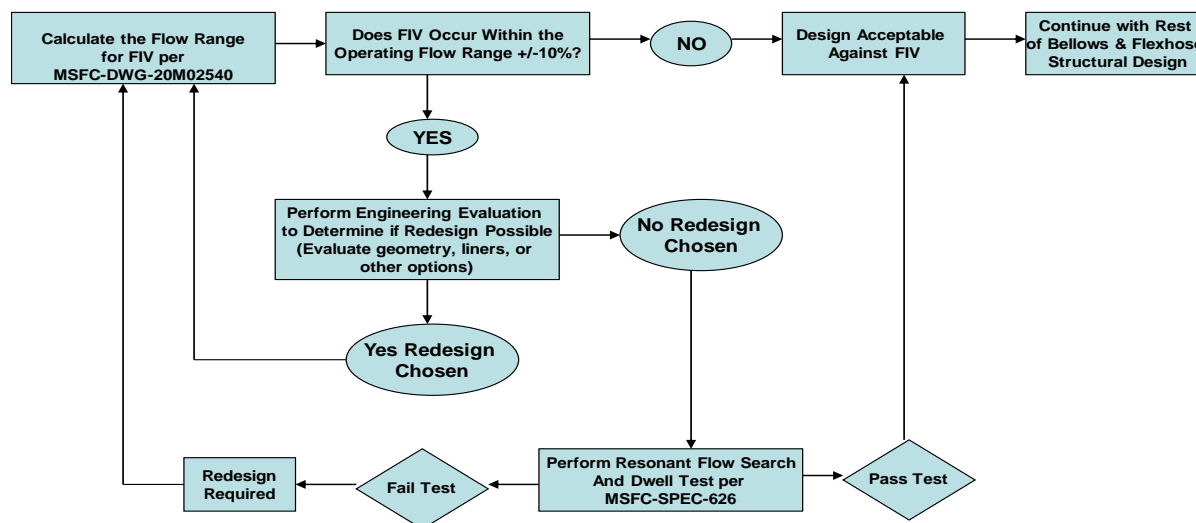


Figure 7.5.3-1: Design Acceptability Flow Chart

Assessments of Flow-Induced Vibration (FIV) for Flexhoses and Bellows fluid systems will place emphasis on the following:

- Evaluation of flexhose and bellows hazard analysis to determine that components and systems will not cause injury to the crew or damage to flight hardware.
- Review of flexhose and bellows design products to verify that the design requirements are met.
- Evaluation of flexhose and bellows operating range FIV prediction analysis and fatigue life analysis to verify that design requirements are met. Fatigue life analysis may only be applied to those ground systems and equipment bellows and flexhoses, whose failure due to FIV does not result in a situation that jeopardizes the safety of personnel or cause damage/degradation of flight hardware during test operation or ground processing.
- Evaluation of resonant flow test results to verify that design requirements are met.
- Review of flexhose and bellows analysis, test procedures, and results will determine if a Commercial Provider's standards meet the intent of MSFC-DWG-20M02540, *Assessment of*

Flexible Lines for Flow-Induced Vibration and MSFC-SPEC-626, Test Control Document for Assessment of Flexible Lines for Flow Induced Vibration.

7.5.4 Fluid Systems References

Document Number	Revision	Title
SAE-AS-5440	Rev. A	<i>Hydraulic Systems, Military Aircraft, Design and Installation Requirements for</i>

7.6 Propulsion Systems

Launch vehicle propulsion systems (liquid, solid, or hybrid propellants) include boost stage, upper stage, in-space, and auxiliary propulsion systems. These systems may contain propellant tanks, propellant feed, pressurization, thrust vectoring, avionics, and data collection and monitoring systems. Propulsion systems require rigorous design, development, test, and evaluation (DDT&E) programs due to the inherent complexity and tight controls levied by extreme functional and performance targets necessary for ensuring crew safety and mission success. It should also be understood that due to the various types of propulsion systems, the various degrees of complexity of propulsion systems and the heritage of the specific propulsion system technology, there is no succinct method or set of predefined standards for propulsion system certification.

Human-rating a given propulsion system cannot be completely addressed independently from the integrated vehicle architecture. Integration of systems across interfaces is key to understanding how a system could fail. Understanding these hazards and their potential propagation paths allows mitigations, such as fault avoidance (design out), design margins, redundancy, caution and warning devices, and/or special procedures to minimize flight risk.

7.6.1 Propulsion Subsystem Technical Products

Due to the variations in design implementation paths and risk management, it is necessary to invoke a comprehensive strategy that encompasses a wide range of engineering disciplines and practices to ensure the flight worthiness of propulsion systems for manned space vehicles. The propulsion system DDT&E process must be adequately documented and must be available for review throughout all stages of the propulsion system life-cycle.

In this document, many of the transportation certification requirements sections reference technical products that compliment propulsion system design. These products not only apply at the integrated vehicle-level, but are also applicable at the propulsion subsystem and critical components.

Correspondingly, these products, listed in Sections 4.0 through 9.0, do not need to be repeated here, but will be evaluated as critical to propulsion systems, and this section must be augmented with those other technical products to be considered complete.

In further support of design validation, the following products are typically used to substantiate the propulsion system has been adequately designed and verified:

- Functional and performance analysis reports with supporting verification reports/data (e.g., results from Water Hammer Analysis Model(s), system power balance model, motor ballistics analysis, propulsion system dynamics models, induced environments, component-level tests, qualification testing, etc.).

- Propulsion system concept of operations (i.e., integrated system test and checkout, loading operations, timings and hardware operational sequence pre-launch, ignition, mainstage operation, shutdown, abort, and recovery).

7.6.2 Propulsion Subsystem Technical Assessment

Evaluation criteria will establish confidence in the propulsion systems products and processes by assessing the provided documentation products against Government and industry standards, lessons learned, and best practices where they exist and are relevant to the propulsion systems under assessment. The intent is to provide confidence that the design processes and operating procedures are commensurate with accepted standards and meet initial quality expectations for human space flight.

Assessment of propulsion systems will place emphasis on the following:

- Tank slosh damping characteristics are understood through well-anchored slosh analysis, typically through flight or ground test, and are consistent with control system stability analysis.
- Evaluation of models, simulation data, and reports to assess whether models and simulations used in the design and certification of propulsion systems have been properly validated, utilized, and are configuration controlled. Examples include engine performance, ballistics, dynamic thrust vector error, thrust offset error, structural margins, thermal balance, plume impingement, water hammer, propellant slosh, and pogo. Analytical methodology and approach is significant in providing confidence, although it is preferable to have statistically relevant samples of test or flight data via a robust ground test program. Review and analysis of the modeling and analysis methodology will determine if a Commercial Provider's standards meet the intent of JSC 65829, *Loads and Structural Dynamics Requirements for Space Flight Hardware*.
- Evaluation of the propulsion system structural design, verification process, and associated documentation will determine if the Commercial Provider's standards meet the intent of NASA-STD-5012, *Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines*; JSC 65828, *Structural Design Requirements and Factors of Safety for Space Flight Hardware*; and NASA-STD-5019, *Fracture Control Requirements for Spacecraft*.
- Evaluation of propulsion system and component design, and hazard analysis, reliability analysis, separation of critical redundant systems assessments, plans, and operations to determine that integrated components and systems will operate as designed and will not cause injury to the crew or damage to the system.
- Review of acceptance and qualification data (test plans, procedures, and reports) to verify that the CTS (including refurbished or re-flown products) meets performance specifications, demonstrates acceptable quality and workmanship, and is ready to be committed to flight. Review and assessment of subsystems and unit qualification and acceptance data will determine if a Commercial Provider's standards meet the intent of SMC-S-016, *Test Requirements for Launch, Upper-Stage, and Space Vehicles*.
- Review of materials and process control systems to ensure consistent performance and proper functionality of the propulsion system and its components; special emphasis will be focused on solid rocket motors. Review of material and process control system to determine if the Commercial Provider's standards meet the intent of NASA-STD-6016.
- Evaluation of integrated propulsion system test documentation to assure complex phenomenon will be revealed that could possibly remain uncovered prior to flight. Examples include engine-to-engine coupling, component activation dynamics, and engine coupling with unexpected gas/vapor pockets.

- Evaluation of propulsion systems and engines for stability margin to ensure that propulsion performance does not degrade and catastrophic loss of the engine/vehicle will not occur over the propulsion system operating range. Examples include chug, thrust oscillations, pump cavitation, and combustion instability.
- Evaluation of high speed rotating machinery, including identification and quantification of high-risk rotordynamic frequencies.

7.6.3 Propulsion Subsystem References

The following list is intended to provide additional references that NASA has traditionally used and that may help to communicate the standards against which the Commercial Provider's processes will be assessed.

Document Number	Revision	Title
ASME Y14.5M-2009		<i>Dimensioning and Tolerancing</i>
CPIA Publication 655, Jan 1997		<i>Guidelines for Combustion Stability Specifications and Verification Procedures for Liquid Propellant Rocket Engines</i>
MIL-DTL-38999		<i>General Specification for Connectors, Electrical Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded and Breech Coupling), Environment Resistant, Removable for Crimp and Hermetic Solder Contacts</i>
MSFC-HDBK-505	Rev. B	<i>Structural Strength Program Requirements</i>
MSFC-SPEC-164	Rev. C	<i>Specification for Cleanliness of Components for Use in Oxygen, Fuel, and Pneumatic Systems</i>
MSFC-STD-3535	Baseline	<i>Standard for Propellants and Pressurants Used for Test and Test Support Activities at SSC and MSFC</i>
NASA SP-106		<i>The Dynamic Behavior of Liquids</i>
NASA-STD-5001	Rev. A	<i>Structural Design and Test Factors of Safety for Spacecraft Hardware</i>
NPR 8705.2B	Rev. B	<i>NASA Human-Rating Requirements for Space Systems</i>
SAE-AS-1098		<i>Fitting End, Flared Tube, for Seal Ring, Standard Dimensions for, Design Standard</i>
SWRI Publication by Dodge (2000)		<i>The New Dynamic Behavior of Liquids in Moving Containers</i>

7.7 Trailing Deployable Aerodynamic Decelerator

7.7.1 Trailing Deployable Aerodynamic Decelerator (TDAD) Technical Products

A primary requirement for manned spacecraft is to provide safe entry, landing, and recovery on Earth for crew returning from LEO destinations.

Documentation must substantiate that the deceleration system has been adequately designed, manufactured, and verified to demonstrate compliance with the intent of this requirement using documented, accepted standards, and design guides, such as NWC TP 6575, *Parachute Recovery System Design Manual (Knacke)*, and JSSG-2010-12, *Crew Systems Deployable Aerodynamic Decelerator (DAD) Systems Handbook*. JSC 65985, *Requirements for Human Space Flight for the Trailing*

Deployable Aerodynamic Decelerator is the guiding document that defines design, test, and verification methodology for TDAD systems.

Various documented technical standards exist in the TDAD design industry, the adequacies of which are subject to review. As such, the Commercial Provider should provide the following products during the flight certification process to ensure the TDAD has been sufficiently designed and verified:

- Assembly and detailed drawings, drawing tree, and CAD models.
- Concept of operations document, including timing sequences, system geometry, operational uses, and capabilities, as well as its integration with other components and/or subsystems, for the entire life-cycle and each mission phase of the system.
- Interface control documents.
- Design analysis reports (i.e., stress analysis reports, design models, simulations, and analysis).
- Mass properties report comprised of mass values, as well as growth allowance allocations, for all system components.
- Safety documents to include fault tree analysis, Probabilistic Risk Assessment results, hazard analysis, FMEA/Critical Items List (CIL), and reliability and maintainability (R&M) report.
- V&V document defining the plan for (including type), and documenting the results of, V&V activities.
- Qualification and acceptance procedures, including incoming materials lot acceptance.
- Certification Plan.
- Critical manufacturing processes.
- Ground safety analysis report.
- Sustaining Engineering Plan.
- Materials identification and usage list (MIUL).
- Test configuration documents.
- Post-flight test (closure) reports.

7.7.2 TDAD Technical Assessment

Evaluation criteria for submitted documentation, standards, and processes will emphasize the following areas in order to determine whether the Commercial Provider's standards meet the intent of JSC 65985, *Requirements for Human Space Flight for the Trailing Deployable Aerodynamic Decelerator*:

- Overall system function and integrity, to include rate of descent.
- Seam and joint testing reports.
- Test descriptions for any static or dynamic testing (i.e., "test like you fly").
- Component, subsystem, and system requirements traceability.
- Knowledge and verification of environments.
- Design factors of safety and de-rating factors, as directed in NWC TP 6575, *Parachute Recovery System Design Manual*.
- Modeling derivations and assumptions and trajectory and stress analyses to include wake effects on parachute performance and summary of margins of safety.
- Load dispersions for nominal and off-nominal mission cases.
- Safety and reliability approaches and mitigation plans for failure tolerance and failure propagation of each DAD subsystem design to verify single-fault tolerance (loss of crew) and satisfactory propagation methods.

- Testing configuration and number of runs for full-scale system tests (nominal and off-nominal, documenting how close the configuration is to flight), material lots testing, and margin testing.

7.7.3 TDAD References

Document Number	Revision	Title
ADS-TR-61-579		<i>Performance of and Design Criteria for Deployable Aero Decelerators</i>
ARM-10		<i>Apollo Technical Manual - Reliability</i>
ASTM D6193		<i>Standard Practice for Stitches and Seams</i>
JPR 8080.5		<i>JSC Design and Procedural Standards</i>
JSSG-2010-12		<i>Crew Systems Deployable Aerodynamic Decelerator (DAD) Systems Handbook</i>
MIL-H-7195		<i>General Specification for Parachute Hardware</i>
MIL-STD-129		<i>Marking for Shipment and Storage</i>
NASA-STD-3001 Vol. 1-2		<i>Space Flight Human System Standards</i>
NASA-STD-5005C		<i>Standard for the Design and Fabrication of Ground Support Equipment</i>
NASA-STD-5019		<i>Fracture Control Requirements for Space Flight Hardware</i>
NASA-STD-6016		<i>Standard Materials and Processes Requirements for Spacecraft</i>
NPR 6000.1		<i>Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment, and Associated Components</i>
NPR 8705.2		<i>NASA Human-Rating Requirements for Space Systems</i>

8.0 Materials, Processes, and Fracture Control

8.1 Fracture Control

8.1.1 Fracture Control Technical Products

It is NASA policy that fracture control be imposed on all human-rated space flight hardware to ensure safety by mitigating the risk of catastrophic failure due to the presence of flaws.

It is expected that an FCP and an FCSR consistent with the intent of NASA-STD-5019, *Fracture Control Requirements for Spacecraft* will be generated.

8.1.2 Fracture Control Technical Assessment

In order to substantiate that the Commercial Provider has met the intent of NASA-STD-5019, the FCP will be evaluated to assure that specific fracture control methodology and procedures are in place for the prevention of catastrophic failure associated with propagation of cracks, flaws, or damage during fabrication, testing, handling, transportation, and operational life. The plan should also include a description of how the prime contractor or vehicle owner imposes any applicable fracture control requirements onto subcontractors and suppliers.

It is expected that the FCSR will provide the following information as described in NASA-STD-5019, Section 6.3:

- Sufficient information to ensure certification that fracture control requirements have been met.
- Sufficient hardware descriptions, including sketches and figures, to convey a clear understanding of the hardware elements and their functions.
- Supporting detailed documentation.
- An accounting of all parts and their disposition for fracture control.
- For failsafe parts, identification of NDE and inspection plans, Material Usage Agreements (MUAs), discrepancies, or deviations from design that affect fracture control and flaw detections and their resolutions.
- Identification of any flaws that may be accepted on risk by the Program authority.

8.1.3 Fracture Control References

Document Number	Revision	Title
SSP 30558		<i>Fracture Control Requirements for Space Station</i>
NASA-HNBK-5010 Volume 1		<i>Fracture Control Implementation Handbook for Space Flight Hardware other than Composite or Bonded Parts</i>
NASA-HNBK-5010 Volume 2		<i>Fracture Control Implementation Handbook for Space Flight Hardware Composite or Bonded Parts</i>
JSC 25863B		<i>Fracture Control Plan for JSC Space-Flight Hardware</i>

8.2 Materials and Processes

8.2.1 Materials and Processes Technical Products

In order to validate the flight readiness of any hardware or system, there are minimum requirements for materials and processes (M&P) that must be met. Included are M&P requirements used in design, fabrication, and testing of flight components for both manned and unmanned spacecraft systems.

All hardware is covered by M&P requirements, including vendor-designed, off-the-shelf, and vendor-furnished items. The prime contractor is responsible to flow down these requirements to their subcontractors and lowest component-level suppliers. To prevent damage or contamination of flight hardware, also covered are interfacing ground support equipment, hardware processing equipment, hardware packaging, and hardware shipment.

The Commercial Provider will be responsible for meeting the intent of NASA-STD-6016 requirements. This may be accomplished through the development of an M&P Selection, Control, and Implementation Plan, or by constructing a matrix of applicable and non-applicable paragraphs.

It is recommended that within the construct of the Implementation Plan or applicability matrix, that the following subject matter be specifically addressed:

- NDE Plan.
- Contamination Control Plan.
- Finishes Plan.
- Design allowables.
- MUAs.
- Materials and Processes Identification and Usage List (MIUL).

8.2.2 Materials and Processes Technical Assessment

Many of the system sections of this document identify specific subsets of the products and technical assessments expected for M&P. Although these subsets are of especial interest to the specific system, it is noted that the M&P products and technical assessments identified in this section are expected for all hardware systems, regardless of whether they are specifically identified under those systems or not.

A review of the submitted M&P documentation and plans will focus on the following elements to substantiate that the Commercial Provider's standards for M&P meet the intent of NASA-STD-6016:

- Assurance that the M&P used are selected by considering the worst-case operational requirements for the particular application and the design engineering properties of the candidate materials.
- Identification of applicable standards and specifications, including Government, industry, and company generated.
- Documentation of the methods used to control compliance of requirements by subcontractors and vendors.
- Methodology for coordinating, approving, and tracking all engineering drawings, engineering orders, and other documents that establish or modify materials and/or processes usage.

8.3 Natural Environments

“Natural environments,” as the term is used here, refers to the environments that are not the result of intended human activity or intervention. They consist of a variety of external environmental factors

(most of natural origin and a few of human origin) which impose restrictions or otherwise impact the development or operation of aerospace vehicles. Natural environment technical areas are generally grouped into the following classifications:

- a. Terrestrial environments at pre-launch, launch, abort, and normal and abort landing sites (e.g., winds, temperatures, pressures, surface roughness, sea state, etc.).
- b. Space environments (e.g., ionizing radiation, orbital debris, meteoroids, thermosphere density, plasma, solar, Earth, and lunar-emitted thermal radiation, etc.).
- c. Destination environments.

These factors are outside the actual control of the Program, so the Program controls the risks and “definition” of these factors (i.e., the models, data sets, and descriptions) in order to maintain a uniform, consistent, and verifiable baseline for hardware development. NASA considers it important that the natural environment be maintained under good configuration management by the Program (i.e., the Commercial Provider, in this case). The intent is to keep a unified specification of the natural environments over which all flight elements can operate.

8.3.1 Natural Environment Technical Products

Natural environmental specifications are derived from the DRMs specific for a program and are designed to match the program operational, risk, and cost goals as much as possible. Coordination between environment specifications and the DRMs must be maintained. Note that these specifications are actually a support to the design process because the data and models specified are frequent inputs to the engineering analysis. Various approaches for documenting natural environments may be used, but the following basic elements of the product structure are typically needed:

- a. Top-Level Natural Environment Specification - This document defines the environmental parameter limits (maximum and minimum values, energy spectra or precise model inputs, assumptions, model options, etc., consistent with Program risk policy), to be used in the design and development of all Program flight elements. It is also used as a reference by ground support hardware, since GSE must support the operation of the flight hardware.
- b. Detail-Level Environment Specification – Typically, this is a compilation of the natural and derived environments (natural environments as modified by the flight hardware) and induced environments applicable at the box or vehicle zone-level. This information is needed in the design process and for subcontract specifications (where applicable).
- c. Applicability Matrices - These are detailed breakdowns of what environments apply to each hardware element or system. The matrix, at least at top-level, should address all mission phases, because environment specifications will change with each phase, and separation of active versus inactive hardware may also be needed. These may be included within detailed-level specification, if desired.
- d. Launch Commit and Operational Flight Rules - One or more documents that specify the environmental limits on launch, landing, and flight operations. These rely heavily upon the top-level specification, because the top-level specification defines the limits of the flight hardware capability; however, the technical data and models used there are generally not appropriate for the operational phase. The design phase is based largely on climatic data and statistical models, while real-time observations and forecast models are appropriate for operational support.

8.3.2 Natural Environment Technical Assessments

Most environments must be addressed at multiple levels, depending upon the architecture. Thus, the process of identifying where an environment is a key driver and where it is just a routine input to the engineering process highlights the importance of the flow down from the top-level specification to the detailed-level specification. The key drivers may be handled by robust design, by accepting risk, or by operational mitigation and constraints. Pre-flight transportation and storage specifications are addressed by environment control, packaging, or environment monitoring to assure the flight hardware is not adversely affected. For all phases, one is looking for thoroughness in the approach to eliminate latent damage to inactive hardware, as well as complete coverage of all active phases. Thoroughness also implies accounting for the less prominent environment effects (i.e., spacecraft charging, ionizing radiation single event effects to the launch vehicle, orbital debris threats to exposed cables or instruments, etc.).

In the development of the top-level design specifications, one is looking for widely recognized, peer reviewed models and limits derived from data sets with long periods of record and good quality, directly applicable data. Uncertainties should be defined wherever possible. Some useful models that meet these criteria are listed in the following section. Note that these models do not include margins, and they are generally not added so that margin is not doubled up with the engineering margins.

Environment assessments for the Commercial Providers have an added complexity in that they must address environment-related ISS requirements from SSP 50808. Many Space Station environment specifications have not been updated, so they represent knowledge of the environment that is several decades old. Generally, these older specifications can be considered to “do the job,” but there are some exceptions and concerns. Ionizing radiation values in these older specifications are considered overly conservative for single event effects. The Providers should work carefully with both the CCP and the ISS Program Offices to assure a suitable resolution of these issues.

8.3.3 Natural Environment Design References

The following list includes documents and environment models that have been found to be particularly useful and suitable to support space flight hardware development activities. The models listed may NOT be appropriate for operational applications; operational models are selected based on different criteria.

Document Number	Revision	Title
AE9/AP9		<i>Trapped Energetic Electron and Proton Environments (NSSDC/SDC-A-R&S 76-06 and NSSDC WDC-A-R&S 91-24)</i>
CREME96		<i>Cosmic Ray Effects on Microelectronics, Single Event Upset Environments. Do not use for electrons.</i>
E. Normand & T.J. Baker, 1993		<i>Altitude and Latitude Variations in Avionics SEU and Atmospheric Neutron Flux</i> IEEE Transactions On Nuclear Science, Vol. 40, No. 6, December 1993
Edwards, Normand & Dyer, 2004		<i>Technical Standard for Atmospheric Radiation Single Event Effects (SEE) on Avionics Electronics</i> 0-7803-8697-3/04/\$20.00 ©2004 IEEE

Document Number	Revision	Title
Earth-GRAM 2010		<i>Global Reference Atmosphere Model (available from EV44, MSFC)</i>
Emission of Solar Protons		<i>Solar Proton Event, Galactic Cosmic Ray Environments, Geomagnetic Shielding</i>
International Geomagnetic		<i>Terrestrial Magnetic Field Reference Field</i>
International Reference Ionosphere		<i>Cold Low Earth Orbit Plasma Environments Ionosphere</i>
Jacchia-Bowman	2008	<i>Thermosphere drag (Available within Earth-GRAM 2010)</i>
King 1972 SPE Model		<i>Crew Dose for Exposure to Solar Particle Event, Not Recommended for Avionics Applications. Journal of Spacecraft and Rockets, 11, 401, 1974</i>
MEM		<i>Meteoroid Engineering Model (available from EV44, MSFC)</i>
MSIS-86		<i>Atomic oxygen (available within Earth-GRAM 2010)</i>
MVWP		<i>Monthly Vector Wind Model (See NASA/TM 2008-215633)</i>
NASA/TM-2001-211221		<i>Guidelines for the Selection of Near-Earth Thermal Environment Parameters for Spacecraft Design</i>
NASA/TM-2008-215633		<i>Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development, 2008 Revision</i>
O'Neill-Badhwar GCR Model	2006	<i>O'Neill, P.M., Badhwar – O'Neill Galactic Cosmic Ray Model Update Based on Advanced Composition Explorer (ACE) Energy Spectra from 1997 to Present, Advances in Space Research, Vol. 37, pp 1727-1733, 2006</i>
ORDEM 3.0		<i>Orbital Debris Engineering Model from the JSC Orbital Debris Program Office</i>
Solar Irradiance Platform		<i>UV-EUV</i>

9.0 Software

9.1 Flight and Ground Software

9.1.1 Flight and Ground Software Technical Products

A review of Commercial Provider documentation covering the requirements, design, implementation, test and verification, operation, and management of safety critical software products will be performed to ensure that they address the intent of appropriate NASA standards and specifications. Of interest are those items classified as 'Class A' according to the definition contained in Appendix E of NPR 7150.2A, specifically ground and flight software 'developed and/or operated by or for NASA that is needed to perform a primary mission objective of human space flight and directly interacts with human space flight systems,' and that has direct impacts on the health and safety of the crew. NASA will negotiate with each Commercial Provider to jointly identify the specific software products that fall into this category.

Documentation related to any software models or simulations whose results are used to make critical decisions regarding design, development, manufacturing, and ground or flight operations that may impact human safety or Program defined mission success criteria will also be reviewed. Of particular interest are the methods and procedures used for verification, validation, and quantification of uncertainty that is used to assess and certify the credibility of the model.

Special emphasis will be placed on those software items that are determined to be of a safety critical nature. As part of a system-wide hazard analysis conducted on both flight and ground segments, specific components or subsystems that are able to cause, control, detect, or mitigate safety hazards are identified. For those hazards with potentially catastrophic consequences, such as loss of crew or loss of vehicle, any software products associated with those functions should be included in the system hazard analyses to the level where appropriate software and hardware controls and mitigations can be identified. The results of this study should outline the methods by which the design or testing of this software may be used to mitigate these possibilities by either preventing the hazardous behavior from occurring, reducing the likelihood of a catastrophic event from occurring, or minimizing the negative effects of a safety critical fault or failure. Additional information regarding the process for identifying and classifying safety critical software, as well as methods for performing a software safety analysis and creating a software safety report, may be found in NASA-STD-8719.13B, *Software Safety Standard* and NASA-GB-8719.13, *Software Safety Guidebook*.

Also of interest to NASA is how the Commercial Provider will address the intent of appropriate requirements contained in the NASA Security of Information Technology Standard designed to adequately ensure that the confidentiality, integrity, and availability of critical software components. A thorough review of appropriate software security plans, policies, and procedures concerning the management of safety critical software components will be conducted to determine that sufficient security controls and protection are implemented.

Specific documents to be examined include the full set of artifacts produced during the software life-cycle process as conducted in accordance with commonly accepted industry standards (e.g., DOD-STD-2167A, MIL-STD-498, IEEE J-STD-016, ISO 12207, etc.) and will normally include, but not be limited to, some or all of the following:

- Software management plans.
- Software security plans for development environment of Class A products.
- Software development plans.
- Software requirements specifications.
- Software operations concept documents.
- Software design documents.
- Software product specifications.
- Software interface design documents.
- Software test plans.
- Software test procedures.
- Software test reports.
- Software user's manuals.
- Software Safety Plan.
- Software quality report.

9.1.2 Flight and Ground Software Technical Assessment

A review of the software technical products will substantiate that the Commercial Provider software design processes meet the intent of NPR 7150.2A, *NASA Software Engineering Requirements*, for Class A software.

Specific areas to be focused on during this review include how critical software components will be designed, developed, tested, managed, and used in the overall design and operation of the vehicle, and how those components will ensure a safe and habitable environment for the crew and support the detection and mitigation of any risks to their well being. These factors are the result of acquired knowledge and lessons learned from over fifty years of NASA human space flight experience and generally involve topics, such as:

- Fault tolerance.
- Failure detection, identification, and isolation or recovery.
- Similar or dissimilar redundancy.
- Autonomous operation of safety critical functions.
- Manual override of automatic functions.
- Extent of ground and crew visibility into system operation and performance.
- Amount of crew involvement and interaction required.
- Accurate and timely notifications of faults and anomalies.
- Command authentication and validation, including response to inadvertent commanding.
- Ground monitor and control of vehicle systems without crew involvement.
- Maintaining vehicle control and crew environment during abort scenarios.

9.1.3 Flight and Ground Software References

Document Number	Revision	Title
NPR 2810.1A	Rev. A	<i>Security of Information Technology</i>
NPR 7150.2A	Rev. A	<i>NASA Software Engineering Requirements</i>
NASA-STD-7009		<i>Standard for Models and Simulations</i>

Appendix A: Acronyms

Acronyms	Phrase
ACE	Advanced Composition Explorer
CCP	Commercial Crew Program
CIL	Critical Items List
COPV	Composite Overwrapped Pressure Vessel
COTS	Commercial Off the Shelf
CTS	Crew Transportation System
DDT&E	Design, Development, Test, and Evaluation
DRM	Design Reference Mission
EEE	Electrical, Electronic, and Electromechanical
EMC	Electromagnetic Compatibility

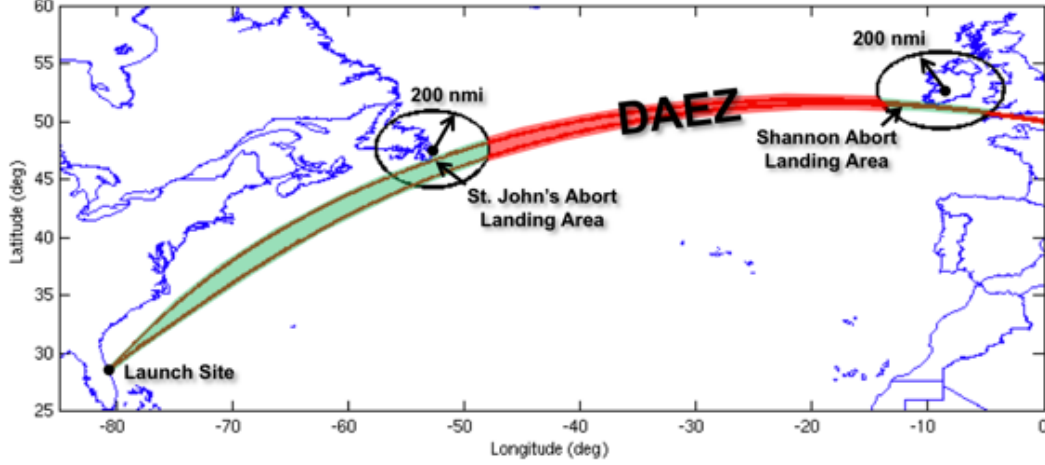
Acronyms	Phrase
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FAA	Federal Aviation Administration
FCP	Fracture Control Plan
FCSR	Fracture Control Summary Report
FMEA	Failure Mode and Effects Analysis
GCR	Galactic Cosmic Radiation
GN&C	Guidance, Navigation, and Control
GSE	Ground Support Equipment
HBM	Human Body Model
Hz	Hertz
IEEE	Institute of Electrical and Electronic Engineers
ISO	International Standards Organization
ISS	International Space Station
IV&V	Independent Verification and Validation
JSC	Johnson Space Center
KSC	Kennedy Space Center
LEO	Low Earth Orbit
M&P	Materials and Processes
MIUL	Materials Identification and Usage List
MMOD	Micro Meteoroid Orbital Debris
MOTS	Military Off the Shelf
MPS	Main Propulsion System
MUA	Materials Usage Agreement
NASA	National Aeronautics and Space Administration
NDE	Nondestructive Evaluation
NHLBB	Non-Hazardous Leak Before Burst
NPD	NASA Policy Document
NPR	NASA Procedural Requirement
p-Static	Precipitation Static
PVD	Purge, Vent, Drain
R&M	Reliability and Maintainability
RF	Radio Frequency
S&MA	Safety and Mission Assurance
SEE	Single Event Effects
SVP	Structural Verification Plan
TDAD	Trailing Deployable Aerodynamic Decelerator
TPS	Thermal Protection System

Appendix B: 1100 Series Definitions

Term	Definition
Abort	The forced early return of the crew when failures or the existence of uncontrolled catastrophic hazards prevent continuation of the mission profile and a return is required for crew survival.
Ambient Light	Any surrounding light source (existing lighting conditions). This could be a combination of natural lighting (e.g., sunlight, moonlight) and any artificial light source provided. For example, in an office there would be ambient light sources of both the natural sunlight and the fluorescent lights above (general office lighting).
Analysis	A verification method utilizing techniques and tools, such as math models, prior test data, simulations, analytical assessments, etc. Analysis may be used in lieu of, or in addition to, other methods to ensure compliance to specification requirements. The selected techniques may include, but not be limited to, task analysis, engineering analysis, statistics and qualitative analysis, computer and hardware simulations, and analog modeling. Analysis may be used when it can be determined that rigorous and accurate analysis is possible, test is not cost effective, and verification by inspection is not adequate.
Annunciate	To provide a visual, tactile, or audible indication.
Approach Ellipsoid	A 4 x 2 x 2 km ellipsoid, centered at the ISS center of mass, with the long axis aligned with the V-Bar.
Approach Initiation	The approach initiation is the first rendezvous maneuver during a nominal approach that is targeted to bring the vehicle inside the ISS approach ellipsoid (AE).
Ascent	The period of time from initial motion away from the launch pad until orbit insertion during a nominal flight or ascent abort initiation during an abort.
Ascent Abort	An abort performed during ascent, where the crewed spacecraft is separated from the launch vehicle without the capability to achieve the desired orbit. The crew is safely returned to a landing site in a portion of the spacecraft nominally used for entry and landing/touchdown.
Automated	Automatic (as opposed to human) control of a system or operation.
Autonomous	Ability of a space system to perform operations independent from any ground-based systems. This includes no communication with, or real-time support from, mission control or other ground systems.
Backout	During mission execution, the coordinated cessation of a current activity or procedure and careful return to a known, safe state.
Breakout	Any action that interrupts the nominally planned free flight operations that are intended to place the spacecraft outside of a threatening location to the cooperative vehicle. This may be an automated or manually executed action. For the ISS, the area within which a vehicle poses a threat to ISS is called the Approach Ellipse.
Cargo	An item (or items) required to maintain the operability of the ISS and/or the health of its crew, and that must be launched and/or returned.

Catastrophic Event	An event resulting in the death or permanent disability of a ground closeout or flight crewmember, or an event resulting in the unplanned loss/destruction of a major element of the CTS or ISS during the mission that could potentially result in the death or permanent disability of a flight crewmember.
Catastrophic Hazard	A condition that could result in the death or permanent disability of a ground closeout or flight crewmember, or in the unplanned loss/destruction of a major element of the CTS during the mission that could potentially result in the death or permanent disability of a flight crewmember.
Command	Directive to a processor or system to perform a particular action or function.
Communications Coverage	Communication coverage is defined as successful link availability for nominal ascent and entry trajectories.
Communications Link	A communication link is established, whereas the received commands and voice from the CVCC to the spacecraft and the transmitted health and status data, crew health and medical related data, voice, telemetry, and transmitted launch vehicle and spacecraft engineering data are received.
Consumable	Resource that is consumed in the course of conducting a given mission. Examples include propellant, power, habitability items (e.g., gaseous oxygen), and crew supplies.
Continental U.S. Airport	An airport within the continental United States capable of accommodating executive jet aircraft similar to the Gulfstream series aircraft.
Contingency	Provisioning for an event or circumstance that is possible but cannot be predicted with certainty.
Contingency Spacecraft Crew Support (CSCS)	CSCS is declared when the spacecraft crew takes shelter on the ISS because the spacecraft has been determined to be unsafe for reentry. In this case, a rescue mission is required to return the spacecraft crew safely.
Crew	Any human onboard the spacecraft after the hatch is closed for flight or onboard the spacecraft during flight.
Crew Transportation System (CTS)	The collection of all space-based and ground-based systems (encompassing hardware and software) used to conduct space missions or support activity in space, including, but not limited to, the integrated space vehicle, space-based communication and navigation systems, launch systems, and mission/launch control.
Critical Decision	Those technical decisions related to design, development, manufacturing, ground, or flight operations that may impact human safety or mission success, as measured by defined criteria.
Critical Fault	Any identified fault of software whose effect would result in a catastrophic event or abort.
Critical Function	Mission capabilities or system functions that, if lost, would result in a catastrophic event or an abort.
Critical Hazard	A condition that may cause a severe injury or occupational illness.
Critical Software	Any software component whose behavior or performance could lead to a catastrophic event or abort. This includes the flight software, as well as ground-control software.
Critical Software/Firmware	Software/Firmware that resides in a safety-critical system that is a potential hazard cause or contributor, supports a hazard control or mitigation, controls

	safety-critical functions, or detects and reports 1) fault trends that indicate a potential hazard and/or 2) failures which lead to a hazardous condition.
Critical (sub)System	A (sub)system is assessed as critical if loss of overall (sub)system function, or improper performance of a (sub)system function, could result in a catastrophic event or abort.
CTS Certification	CTS certification is the documented authorization granted by the NASA Associate Administrator that allows the use of the CTS within its prescribed parameters for its defined reference missions. CTS certification is obtained prior to the first crewed flight (for flight elements) or operational use (for other systems).
CTS Element	One component part of the overall Crew Transportation System. For example, the spacecraft is an element of the CTS.
Deconditioned	“Deconditioned” defines a space crewmember whose physiological capabilities, including musculoskeletal, cardiopulmonary, and neurovestibular, have deteriorated as a result of exposure to micro-gravity and the space environment. It results in degraded crewmember performance for nominal and off-nominal mission tasks.
Definitive Medical Care	An inpatient medical care facility capable of comprehensive diagnosis and treatment of a crewmember's injuries or illness without outside assistance—capable of care of Category I, II, and III trauma patients. Usually a Level I trauma center, as defined by the American College of Surgeons.
Demonstration	A method of verification that consists of a qualitative determination of the properties of a test article. This qualitative determination is made through observation, with or without special test equipment or instrumentation, which verifies characteristics, such as human engineering features, services, access features, and transportability. Human-in-the-loop demonstration is performed for complex interfaces or operations that are difficult to verify through modeling analysis, such as physical accommodation for crew ingress and egress. Demonstration requirements are normally implemented within a test plan, operations plan, or test procedure.
Docking	Mating of two independently operating spacecraft or other systems in space using independent control of the two vehicles' flight paths and attitudes during contact and capture. Docking begins at the time of initial contact of the vehicles' docking mechanisms and concludes when full rigidization of the interface is achieved.
Downrange Abort Exclusion Zone	A geographical region of the North Atlantic Ocean to be avoided for water landings during ascent aborts for ISS missions due to rough seas and cold water temperatures. The region is depicted in Figure B-1. The St. John's abort landing area includes the waters within 200 nmi range to St John's International Airport (47° 37' N, 52° 45' W). The Shannon abort landing area includes the waters within 200 nmi range to Shannon International Airport (52° 42' N, 8° 55' W). Note: The northern and southern bounds of the DAEZ in the ISS Mission DAEZ figure are notional, as these bounds are limited only by steering and cross-range performance along the ascent trajectory and are not formally constrained.

Downrange Abort Exclusion Zone Figure	 <p>Figure B-1 Ascent Downrange Abort Exclusion Zone</p>
Emergency	<p>An unexpected event or events during a mission that requires immediate action to keep the crew alive or serious injury from occurring.</p>
Emergency Egress	<p>Capability for a crew to exit the vehicle and leave the hazardous situation or catastrophic event within the specified time. Flight crew emergency egress can be unassisted or assisted by ground personnel.</p>
Emergency Equipment and Systems	<p>Systems (ground or flight) that exist solely to prevent loss of life in the presence of imminent catastrophic conditions. Examples include fire suppression systems and extinguishers, emergency breathing devices, Personal Protective Equipment (PPE) and crew escape systems. Emergency systems are not considered a leg of failure tolerance for the nominal, operational equipment and systems, and do not serve as a design control to prevent the occurrence of a catastrophic condition.</p>
Emergency Medical Services	<p>Services required to provide the crewmembers with immediate medical care to prevent loss of life or aggravated physical or psychological conditions.</p>
End of Mission	<p>The planned landing time for the entire mission, including the nominal pre-flight agreed to docked mission duration.</p>
Entry	<p>The period of time that begins with the final commitment to enter the atmosphere from orbit or from an ascent abort, and ending when the velocity of the spacecraft is zero relative to the landing surface.</p>
Entry Interface	<p>The point in the entry phase where the spacecraft contacts the atmosphere (typically at a geodetic altitude of 400,000 feet), resulting in increased heating to the thermal protection system and remainder of the spacecraft exterior surfaces.</p>
External Launch Constraint	<p>Conditions outside the CTS provider's control, such as range weather constraints or faults with range or ISS assets, or weather constraints affecting abort rescue forces capabilities. Range weather examples include ability to visually monitor the initial phases of the launch for range safety, etc. Non-weather range constraints include range safety radar and telemetry systems availability, flight termination systems readiness, clearance of air, land, sea, etc.</p>
Failure	<p>Inability of a system, subsystem, component, or part to perform its required function within specified limits.</p>

Failure Tolerance	The ability to sustain a certain number of failures and still retain capability. A component, subsystem, or system that cannot sustain at least one failure is not considered to be failure tolerant.
Fault	An undesired system state and/or the immediate cause of failure (e.g., maladjustment, misalignment, defect, or other). The definition of the term “fault” envelopes the word “failure,” since faults include other undesired events, such as software anomalies and operational anomalies. Faults at a lower level could lead to failures at the higher subsystem or system level.
Flight Configuration	The arrangement, orientation and operational state of system elements and cargo, vehicle cabin layout, flight software mode, and crew complement, clothing and equipment in the applicable mission or ground phase necessary in verification to evaluate the attributes called out in the requirement.
Flight Hardware	All components and systems that comprise the internal and external portions of the spacecraft, launch vehicle, launch abort system, and crew worn equipment.
Flight Operations	All operations of the integrated space vehicle and the crew and ground teams supporting the integrated space vehicle from liftoff until landing.
Flight Phase	A particular phase or timeframe during a mission is referred to as a flight phase. The term “all flight phases” is defined as the following flight phases: pre-launch, ascent, onorbit free-flight, docked operations, deorbit/entry, landing, and post-landing.
Flight Representative	<p>Description of a test-article used in verifications in which the attributes under evaluation are equivalent to the flight article.</p> <p>Example: Human-in-the-loop tests for spacecraft egress must use an equivalent cabin layout, seats and restraints, and hatch configuration and masses. However, the propulsion system does not need to be functional, as it is not under evaluation.</p>
Flight Rules	Established redline limits for critical flight parameters. Each has pre-planned troubleshooting procedures with pre-approved decisions for expected troubleshooting results.
Flight Systems	Any equipment, system, subsystem or component that is part of the integrated space system.
Flight Termination	An emergency action taken by range safety when a vehicle violates established safety criteria for the protection of life and property. This action circumvents the vehicles’ normal control modes and ends its powered and/or controlled flight.
Free Flight Operations	Onorbit operations that occur when the spacecraft is not in contact with any part of the ISS.
Ground Crew	Operations personnel that assist the flight crew in entering the spacecraft, closing the hatch, performing leak checks, and working on the integrated space vehicle at the pad during launch operations.
Ground Hardware	All components and systems that reside on the ground in support of the mission, including the Commercial Vehicle Control Center, launch pad, ground support equipment, recovery equipment, facilities, and communications, network, and tracking equipment.

Ground Processing	The work required to prepare the launch vehicle and spacecraft for mission from final assembly/integration/test through launch and resumes after landing for recovery of crew and cargo.
Ground Support Equipment	Any non-flight equipment, system(s), ground system(s), or devices specifically designed and developed for a direct physical or functional interface with flight hardware to support the execution of ground production or processing. The following are not considered to be GSE: <ul style="list-style-type: none"> Tools designed for general use and not specifically for use on flight hardware. Ground Support Systems that interface with GSE Facilities.
Habitable	The environment that is necessary to sustain the life of the crew and to allow the crew to perform their functions in an efficient manner.
Hazard	A state or a set of conditions, internal or external to a system, that has the potential to cause harm.
Hazard Analysis	The process of identifying hazards and their potential causal factors.
Health and Status Data	Data, including emergency, caution, and warning data, that can be analyzed or monitored describing the ability of the system or system components to meet their performance requirements.
Human Error	Either an action that is not intended or desired by the human or a failure on the part of the human to perform a prescribed action within specified limits of accuracy, sequence, or time that fails to produce the expected result and has led or has the potential to lead to an unwanted consequence.
Human Error Analysis (HEA)	A systematic approach used to evaluate human actions, identify potential human error, model human performance, and qualitatively characterize how human error affects a system. HEA provides an evaluation of human actions and error in an effort to generate system improvements that reduce the frequency of error and minimize the negative effects on the system. HEA is the first step in Human Risk Assessment and is often referred to as qualitative Human Risk Assessment.
Human-in-the-Loop Evaluation	Human-in-the-loop evaluations involve having human subjects, which include NASA crewmembers as a subset of the test subject population, perform identified tasks in a representative mockup, prototype, engineering, or flight unit. The fidelity of mockups used for human-in-the-loop evaluations may range from low-fidelity, minimal representation, to high-fidelity, complete physical and/or functional representation, relevant to the evaluation. Ideally, the fidelity of human-in-the-loop mockups and tests increases as designs mature for more comprehensive evaluations. Further information on human-in-the-loop evaluations throughout system design can be found in JSC 65995 CHSIP.
Human-System Integration	The process of integrating human operations into the system design through analysis, testing, and modeling of human performance, interface controls/displays, and human-automation interaction to improve safety, efficiency, and mission success.
Ill or Injured	Refers to a crewmember whose physiological and/or psychological well-being and health has deteriorated as a result of an illness (e.g., appendicitis) or injury (e.g., trauma, toxic exposure) and requires medical capabilities exceeding those available on the ISS and transportation to ground-based definitive medical care.

	Ill or injured crewmember performance for nominal and off-nominal mission tasks will be degraded.
Inspection	A method of verification that determines conformance to requirements by the use of standard quality control methods to ensure compliance by review of drawings and data. This method is used wherever documents or data can be visually used to verify the physical characteristics of the product instead of the performance of the product.
Integrated Operations	All operations starting at 90 minutes prior to the ISS Approach Initiation and lasting until the vehicle leaves the ISS Approach Ellipsoid on a non-return trajectory.
Integrated Space Vehicle	The integrated space vehicle includes all flight elements physically connected for the phase of flight from post lift-off until spacecraft separation.
Landing	The final phase or region of flight consisting of transition from descent to an approach, touchdown, and coming to rest.
Landing Site	<p>Supported Landing Sites: A fully supported site on a Continental U.S. land mass or waters directly extending from the coast with CTS recovery forces on station at the time of landing. The landing site zone extends through nominally expected dispersions from the landing site point.</p> <p><u>Designated Primary Landing Site</u> – A supported landing site-intended for landing at the time of spacecraft undock.</p> <p><u>Alternate Landing Site</u> – A supported landing site to which the spacecraft landing can be diverted in the event the deorbit burn is delayed.</p> <p>Unsupported Landing Sites:</p> <p><u>Emergency Landing</u> – Any unsupported site (land or water) arrived at due to critical failures that force immediate return and preclude landing at a designated primary or alternate landing sites.</p>
Launch Commit Criteria	Established redline limits for critical launch parameters. Each has pre-planned troubleshooting procedures with pre-approved decisions for expected troubleshooting results.
Launch Opportunity	The period of time during which the relative position of the launch site, the ISS orbital plane, and ISS phase angle permit the launch vehicle to insert the spacecraft into a rendezvous trajectory with the ISS (northerly launches only due to range constraints). The ISS is in-plane with the Eastern Range approximately every 23 hours and 36 minutes.
Launch Probability	The probability that the system will successfully complete a scheduled launch event. The launch opportunity will be considered scheduled at 24 hours prior to the opening of the launch window.
Launch Vehicle	The vehicle that contains the propulsion system necessary to deliver the energy required to insert the spacecraft into orbit.
Life-Cycle	The totality of a program or project extending from formulation through implementation, encompassing the elements of design, development, verification, production, operation, maintenance, support, and disposal.
Loss of Crew	Death or permanently debilitating injury to one or more crewmembers.
Loss of Mission	Loss of, or the inability to complete enough of, the primary mission objectives, such that a repeat mission must be flown.

Maintenance	The function of keeping items or equipment in, or restoring them to, a specified operational condition. It includes servicing, test, inspection, adjustment/alignment, removal, replacement, access, assembly/disassembly, lubrication, operation, decontamination, installation, fault location, calibration, condition determination, repair, modification, overhaul, rebuilding, and reclamation.
Manual Control	The crew's ability to bypass automation in order to exert direct control over a space system or operation. For control of a spacecraft's flight path, manual control is the ability for the crew to affect any flight path within the capability of the flight control system. Similarly, for control of a spacecraft's attitude, manual control is the ability for the crew to affect any attitude within the capability of the flight/attitude control system.
MCC-H Mission Authority	<ul style="list-style-type: none"> • MCC-H has authority to make final decisions regarding spacecraft operations, including but not limited to Go/No-Go decisions and safety of flight and crew(s). • Beginning with either ISS integrated operations, or 30 minutes before the first required ISS configuration or crew activity in support of the spacecraft on rendezvous (e.g., ISS attitude maneuver, appendage configuration, USOS GPS configuration), whichever comes first. • Ending with either the end of ISS integrated operations, or when ISS is not required to maintain its configuration (e.g., ISS attitude, USOS GPS configuration, or appendages in a configuration) to support the spacecraft, whichever comes later. • Applies anytime the spacecraft free-drift trajectory, including dispersions, is predicted to enter the ISS AE within the next 24 hours.
Mission	The mission begins with entry of the crew into the spacecraft, includes delivery of the crew to/from ISS, and ends with successful delivery of the crew to NASA after landing.
Mission Critical	Item or function that must retain its operational capability to assure no mission failure (i.e., for mission success).
Operations Personnel	All persons supporting ground operations or flight operations functions of the CTS. Examples of these personnel are listed below: Persons responsible for the production, assembly/integration/test, validation, and maintenance of flight hardware, production facilities, launch site facilities, operations facilities, or ground support equipment (GSE). Persons involved with supporting or managing the launch countdown, crew training, or mission during flight. Persons involved in post-flight recovery.
Orbit	This flight phase starts just after final orbit insertion and ends at the completion of the first deorbit burn.
Override	To take precedence over system control functions.
Pad Abort	An abort performed where the crewed spacecraft is separated from the launch vehicle while the launch vehicle remains on the launch pad. As a result, the crewed spacecraft is safely transported to an area which is not susceptible to the dangers associated with the hazardous environment at the launch pad.
Permanent Disability	A non-fatal occupational injury or illness resulting in permanent impairment through loss of, or compromised use of, a critical part of the body, to include

	major limbs (e.g., arm, leg), critical sensory organs (e.g., eye), critical life-supporting organs (e.g., heart, lungs, brain), and/or body parts controlling major motor functions (e.g., spine, neck). Therefore, permanent disability includes a non-fatal injury or occupational illness that permanently incapacitates a person to the extent that he or she cannot be rehabilitated to achieve gainful employment in their trained occupation and results in a medical discharge from duties or civilian equivalent.
Portable Fire Suppression System	A system comprised of one or more portable handheld fire extinguishers and access ports. These access ports allow the user to discharge fire suppressant into enclosed areas with potential ignition sources. See also 3.10.12.2 Use of Hazardous Chemicals.
Post-Landing	The mission phase beginning with the actual landing event when the vehicle has no horizontal or vertical motion relative to the surface and ending when the last crewmember is loaded on the aircraft for return to JSC.
Proximity Operations	The flight phase including all times during which the vehicle is in free flight beginning just prior to Approach Initiation (AI) execution and ending when the vehicle leaves the Approach Ellipsoid (AE).
Quiescent Docked Operations	The state of the CTS spacecraft while it is docked to the ISS with hatches open and ISS services, as called out in SSP 50808, connected and operational. From this state, the vehicle can support immediate ingress and transition into safe haven in the case of an emergency.
Recovery	The process of proceeding to a designated nominal landing site, and retrieving crew, flight crew equipment, cargo, and payloads after a planned nominal landing.
Reliability	The probability that a system of hardware, software, and human elements will function as intended over a specified period of time under specified environmental conditions.
Rendezvous	The flight phase of executing a series of onorbit maneuvers to move the spacecraft into the proximity of its target. This phase starts with orbit insertion and ends just prior to the approach initiation.
Safe Haven	A functional association of capabilities and environments that is initiated and activated in the event of a potentially life-threatening anomaly and allows human survival until rescue, the event ends, or repair can be affected. It is a location at a safe distance from or closed off from the life-threatening anomaly.
Safety	The absence from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment.
Safety Critical	A condition, event, operation, process, function, equipment or system (including software and firmware) with potential for personnel injury or loss, or with potential for loss or damage to vehicles, equipment or facilities, loss or excessive degradation of the function of critical equipment, or which is necessary to control a hazard.
Search and Rescue	The process of locating the crew, proceeding to their position, and providing assistance.
Software	Computer instructions or data stored electronically. Systems software includes the operating system and all the utilities that enable the computer to function.

	Applications software includes programs that do real work for users, such as word processors, spreadsheets, data management systems, and analysis tools. Software can be Commercial Off-The-Shelf (COTS), contractor developed, Government furnished, or combinations thereof.
Spacecraft	All system elements that are occupied by the crew during the space mission and provide life support functions for the crew. The crewed element includes all the subsystems that provide life support functions for the crew.
Space System	The collection of all space-based and ground-based systems (encompassing hardware and software) used to conduct space missions or support activity in space, including, but not limited to, the integrated space vehicle, space-based communication and navigation systems, launch systems, and mission/launch control.
Stowage	The accommodation of physical items in a safe and secure manner in the spacecraft. This does not imply that resources other than physical accommodations (e.g., power, thermal, etc.) are supplied.
Subsystem	A secondary or subordinate system within a system (such as the spacecraft) that performs a specific function or functions. Examples include electrical power, guidance and navigation, attitude control, telemetry, thermal control, propulsion, structures subsystems. A subsystem may consist of several components (hardware and software) and may include interconnection items such as cables or tubing and the support structure to which they are mounted.
System	The aggregate of the ground segment, flight segment, and workforce required for crew rescue and crew transport.
Task Analysis	Task analysis is an iterative human-centered design process through which user tasks are identified and analyzed. It involves 1) the identification of the tasks and subtasks involved in a process or system, and 2) analysis of those tasks (e.g., who performs them, what equipment is used, under what conditions, the priority of the task, dependence on other tasks). The focus is on the human and how they perform the task, rather than the system. Results can help determine the hardware or software that should be developed/used for a particular task, the ideal allocation of tasks to humans vs. automation, and the criticality of tasks, which drive design decisions. Further information on task analysis can be found in JSC 65995 CHSIP, Section 4.1.
Test	A method of verification in which technical means, such as the use of special equipment, instrumentation, simulation techniques, and the application of established principles and procedures, are used for the evaluation of components, subsystems, and systems to determine compliance with requirements. Test will be selected as the primary method when analytical techniques do not produce adequate results; failure modes exist, which could compromise personnel safety, adversely affect flight systems or payload operation, or result in a loss of mission objectives. The analysis of data derived from tests is an integral part of the test program and should not be confused with analysis as defined above. Tests will be used to determine quantitative compliance to requirements and produce quantitative results.
Time-Critical Cargo	Cargo that requires late stowage pre-launch (within 24 hours of launch) and early removal post-landing (within 1 hour of crew egress).
Transport	Launch of crew and cargo to and return from the ISS.

Validation	Proof that the product accomplishes the intended purpose. May be determined by a combination of test, analysis, and demonstration.
Verification	Proof of compliance with a requirement or specifications based on a combination of test, analysis, demonstration, and inspection.

Appendix C: Guidance for Critical Models and Simulations

C.1 Scope

Modeling and simulation activities are used widely across the engineering disciplines; therefore, modeling and simulation results must be communicated with accuracy and clarity. The focus of this memo is on critical models and simulations (M&S) and defining recommended practices for communicating results from these critical models and simulations.

C.2 Applicability

Modeling or simulation is accomplished for many reasons; however, a common thread with most modeling and simulation activities is risk mitigation. NASA missions tend to be unique or one-of-a-kind, requiring additional steps to offset the operational risks associated with the implementation of such systems. The determination of whether a model or simulation is categorized as “critical” should be based upon an assessment of the risk posed by the potential use of the M&S. Such M&S risk assessments consider (1) the consequences to human safety or mission success criteria if a decision proves incorrect, and (2) the degree to which M&S results influence a decision. The risk assessment of consequence and M&S results influence can be evaluated with many different techniques. A common assessment technique uses a risk assessment matrix (e.g., Figure C-1).

M&S Results Influence	5: Controlling	(G)	(Y)	(R)	(R)
	4: Significant	(G)	(Y)	(R)	(R)
	3: Moderate	(G)	(Y)	(Y)	(R)
	2: Minor	(G)	(G)	(Y)	(Y)
	1: Negligible	(G)	(G)	(G)	(G)
		IV: Negligible	III: Marginal	II: Critical	I: Catastrophic
		Decision Consequence			

Figure C-1: Sample M&S Risk Assessment Matrix

Definitions for the influence and consequence scales in Figure C-1 are provided in section C.3. For the above example, all M&S that fall within the red risk categories were defined as critical; however, some M&S originally identified as yellow may, after closer examination, fall within the red risk category. As the classification of risk is somewhat subjective, the risk matrix is best used to discuss the risks, rather than as a definitive result. Regardless of the method used, all M&S identified as critical to the decision should follow the communications protocol that follows.

C.2 Communication

Once critical M&S are identified, the next step is to ensure the information generated by that M&S is properly communicated to everyone involved in the decision making process, which has two main components: the results of the M&S-based analysis and the credibility associated with those results.

C.2.1 Results

All critical M&S results should include the following information along with the analysis:

- Results Estimate
- Statement of Uncertainty
- Caveats
- An Understanding of the Associated Risks

Results Estimate:

The notion of a “best estimate of results” may be deceptively simple; however, it is critically important to never lose sight of the fact that all M&S results are *estimates* of a given system’s response (behavior), and not necessarily the exact response to expect. There is no generally applicable definition of “best estimate” and that the results presented need to be carefully examined to ensure that it meets the needs of the situation, which is similar to ensuring that the model of the system matches the system and problem.

Questions to ask when presented with a best estimate of an M&S-based analysis include:

- What definition of best estimate was assumed by the analyst?
 - Mean? Median? Mode? Maximum Likelihood?
 - Were higher-order statistical measures considered?
 - Were outliers removed?
- Does everyone agree that this is the best definition for the problem at hand?

Quantitative Statement of Uncertainty:

As the results of an analysis are based on a *model* of the real system and its environment with concomitant assumptions, approximations, estimates, and other uncertainties, it is usually inappropriate and possibly misleading to present the outcome of an analysis as a single definitive result, at least without some qualification. Because of imperfections in models and data, models inherently contain uncertainties, which subsequently propagate into the results of a simulation analysis. Therefore, both the estimated results and the associated uncertainties in those results should be reported.

Questions to be addressed include:

- What are the magnitudes of the uncertainties in the results of this analysis?
- Are the uncertainties understandable and reasonable?
- How does the uncertainty influence the decision at hand?
- How does the uncertainty influence the risk associated with the decision at hand?

Caveats:

For M&S-based analyses, a caveat is defined as follows:

Modifying or cautionary information to consider when evaluating or interpreting the results of an M&S-based analysis.

In a given M&S analysis, a caveat is information pertinent to the results presented that should at a minimum be noted, or should provide caution to the recipient (e.g., decision maker). Examples of possible caveats are:

- Unachieved acceptance criteria.

- Violation of any assumptions of any model used.
- Violation of the limits of operation.
- Execution warning and error messages.
- Unfavorable outcomes from the intended use and setup/execution assessments.
- Waivers to any of the requirements in this standard.

An Understanding of the Associated Risks:

The risks associated with a given decision should be understood along with the influences of an M&S-based analysis on that decision. The acceptability of the risks of a particular course of action is assessed with respect to the consequences and likelihood of their occurrence (Figure C-2).

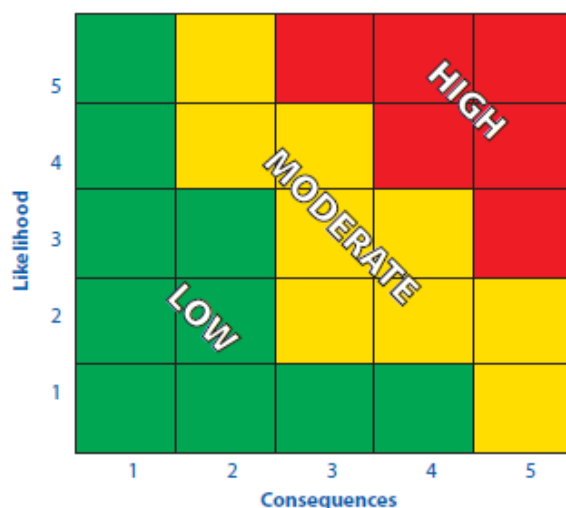


Figure C-2: Risk Assessment Matrix

C.2.2 Credibility Assessment

The second part of communicating information about critical M&S is the credibility assessment. There are no pass/fail criteria for M&S analysis credibility assessments. The intent is to provide an accurate and consistent analytical assessment of the M&S that is used to start a dialogue between the people doing the M&S and the decision-makers. It is also important to note that the credibility assessment is performed on the M&S analysis results, NOT on the people performing the analysis. The credibility assessment addresses eight factors that contribute to the credibility of M&S results:

- Verification
- Validation
- Input pedigree
- Results uncertainty quantification
- Results robustness
- Use history
- M&S process, product, and data management
- Qualifications of applicable personnel (People Qualifications)

Figure C-3 is a 1-page *example* format used to document an M&S credibility assessment. Definitions of each of the eight categories, as well as a description of the scaling, are provided in section C.4. It is important to note that in the early design phases of a program or project, these factors may have low credibility assessments. As the program or project matures, along with it the M&S and input data, it is expected that the credibility assessment will correspondingly increase. It is expected that program/project management in association with the technical authority define and change the expectations for credibility throughout the lifecycle. The credibility assessment is meant to communicate a snapshot of the state of the M&S at the time the analysis was performed. However, it is commonplace at major reviews to have criteria against which to measure progress. Section C.5 provides some examples of the types of credibility assessments ratings expected at various phases/milestones in the lifecycle of a program or project. The assessment of credibility can also be enhanced by a technical review of the M&S effort. This can encompass the development and use of the M&S spanning at least the first five factors of credibility and potentially all eight.

4								
3								
2								
1								
0								
	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications

Figure C-3: Sample Credibility Assessment Template

M&S Development

Verification - Supporting Information

Validation - Supporting Information

M&S Operations

Input Pedigree - Supporting Information

Results Uncertainty - Supporting Information

Results Robustness - Supporting Information

Supporting Evidence

Use History - Supporting Information

M&S Process, Product, and Data Management - Supporting Information

People Qualifications - Supporting Information

C.3 Sample M&S Risk Assessment Matrix Definitions

Decision Consequence

Consequence classifications assess the impact of a decision that proves incorrect. The number of Consequence levels and most of the language is taken from NPR 8000.4. The last item in each class description has been added to address impact upon mission success criteria, such as science objectives.

- a. Class IV - Negligible. A poor decision may result in the need for minor first aid treatment but would not adversely affect personal safety or health; damage to facilities, equipment, or flight hardware more than normal wear and tear level; internal schedule slip that does not impact internal development milestones; cost overrun less than 2 percent of planned cost; all mission success criteria met, with at worst minor performance degradations.
- b. Class III - Moderate. A poor decision may result in minor injury or occupational illness, or minor property damage to facilities, systems, equipment, or flight hardware; internal schedule slip that does not impact launch date; cost overrun between 2 percent and not exceeding 15 percent of planned cost; a few (up to 25 percent) mission success criteria not met due to performance degradations.
- c. Class II - Critical. A poor decision may result in severe injury or occupational illness, or major property damage to facilities, systems, equipment, or flight hardware; schedule slippage causing launch date to be missed; cost overrun between 15 percent and not exceeding 50 percent of planned; many (between 25 percent and 75 percent) mission success criteria not met due to substantial performance degradations.
- d. Class I - Catastrophic. A poor decision may result in death or permanently disabling injury, facility destruction on the ground, or loss of crew, major systems, or vehicle during the mission; schedule slippage causing launch window to be missed; cost overrun greater than 50 percent of planned cost; most (more than 75 percent) mission success criteria not met due to severe performance degradations.

M&S Influence

Influence estimates the degree to which M&S results influence program/project engineering decisions. (Engineering decisions include determination of whether design requirements have been verified.)

- a. Influence 1 - Negligible. Results from the M&S are a negligible factor in engineering decisions. This includes research on M&S methods, and M&S used in research projects that have no direct bearing on program/project decisions.
- b. Influence 2 - Minor. M&S results are only a minor factor in any program/project decisions. Ample flight or test data for the real system in the real environment are available, and M&S results are used just as supplementary information.
- c. Influence 3 - Moderate. M&S results are at most a moderate factor in any program/project decisions. Limited flight or test data for the real system in the real environment are available, but ample flight or test data for similar systems in similar environments are available.
- c. Influence 4 - Significant. M&S results are a significant factor in some program/project decisions, but not the sole factor for any program/project decisions. Ample flight or test data for similar systems in similar environments are available.
- d. Influence 5 - Controlling. M&S results are the controlling factor in some program/project decisions. Neither flight nor test data are available for essential aspects of the system and/or the environment.

C.4 M&S Credibility Assessment Template Definitions

The M&S credibility assessment consists of eight factors grouped into three categories, as shown below and in Figure 3. A five-level assessment of credibility is defined for each factor.

M&S Development

Verification: Were the models implemented correctly, and what was the numerical error/uncertainty?

Validation: Did the M&S results compare favorably to the referent data, and how close is the referent to the real-world system?

M&S Operations

Input Pedigree: How confident are we of the current input data?

Results Uncertainty: What is the uncertainty in the current M&S results?

Results Robustness: How thoroughly are the sensitivities of the current M&S results known

Supporting Evidence

Use History: Have the current M&S been used successfully before?

M&S Management: How well managed were the M&S processes, products, and data?

People Qualifications: How qualified were the personnel?

Figure C-4 is the scale definition used in the sample Credibility Assessment Template in Figure C-3.

Level	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications
4	Numerical errors small for all important features.	Results agree with real-world data.	Input data agree with real-world data.	Non-deterministic & numerical analysis.	Sensitivity known for most parameters; key sensitivities identified.	De facto standard.	Continual process improvement.	Extensive experience in and use of recommended practices for this particular M&S.
3	Formal numerical error estimation.	Results agree with experimental data for problems of interest.	Input data agree with experimental data for problems of interest.	Non-deterministic analysis.	Sensitivity known for many parameters.	Previous predictions were later validated by mission data.	Predictable process.	Advanced degree or extensive M&S experience, and recommended practice knowledge.
2	Unit and regression testing of key features.	Results agree with experimental data or other M&S on unit problems.	Input data traceable to formal documentation.	Deterministic analysis or expert opinion.	Sensitivity known for a few parameters.	Used before for critical decisions.	Established process.	Formal M&S training and experience, and recommended practice training.
1	Conceptual and mathematical models verified.	Conceptual and mathematical models agree with simple referents.	Input data traceable to informal documentation.	Qualitative estimates.	Qualitative estimates.	Passes simple tests.	Managed process.	Engineering or science degree.
0	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.	Insufficient evidence.
	M&S Development		M&S Operations			Supporting Evidence		

Figure C-4: Sample Credibility Assessment Scale

C.4 Example Credibility Assessment Ratings for Various Milestones

Concept Development Phase Example

4								
3								
2								
1								
0								
	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications

Pre-SRR Example

4								
3								
2								
1								
0								
	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications

SRR Example

4								
3								
2								
1								
0								
	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications

PDR Example

4								
3								
2								
1								
0								
	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications

CDR Example

4								
3								
2								
1								
0								
	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications

FRR Example

4								
3								
2								
1								
0								
	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications

Post-Flight Example

4								
3								
2								
1								
0								
	Verification	Validation	Input Pedigree	Results Uncertainty	Results Robustness	Use History	M&S Management	People Qualifications